Greenhouse Gases From Small Scale Combustion in Developing Countries

A Study in India

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Glossary of Abbreviations used

Fw1 = Fuel wood1 (Eucalyptus)
Fw2 = Fuel wood2 (Acacia)
CR1 = Crop residue1 (mustard stalk)
CR2 = Crop residue2 (Paddy straw)
CC = Charcoal
CB = Char Briquette
KW = Kerosene wick
KP = Kerosene pressure
TM = Traditional mud
Imuv = Improved unvented
Imv_1 = Improved $vented_1$ (mud)
Imv_2 = Improved $vented_2$ (ceramic coating)
3R = 3 rock
EF = Emission factor
RF = Root fuel
DC = Dung cake
BG = Biogas

CHAPTER 1

Introduction

Biofuels have the potential to contribute to global warming as they release greenhouse gases (GHGs) such as carbondioxide(CO_2), Carbon monoxide (CO), methane (CH_4), Nitrous oxide (N_2O) and non methane organic compounds (NMOC) during combustion Much of the CO_2 generated from biomass combustion does not result in net increase in atmospheric concentration because of the fact that CO_2 is captured by terrestrial biomass during photosynthesis Other gases released as the product of incomplete combustion such as CO, 1CH_4 TNMOC and N_2O contribute to global warming either because of higher radiative forcing and due to eventual conversion to CO_2 (Hayes et al., 1994). It is estimated that biomass combustion contributes as much as 20-50 percent tot global emissions (Crutzen et al , 1990, and IPCC 1990) Though a major fraction of the emissions are from large-scale open combustion associated with permanent deforestation, savannah fires, and crop residues, combustion in small-scale devices such as cook-stoves and space heating stoves also releases a significant amount of GHGs A more accurate estimation of emissions from biomass combustion would require an inventory for GHGs from different types of biomass combustion as well as better estimates of amount of biomass burnt.

In recent years, estimates of emission factors for GHGs from open large-scale combustion have been made in the laboratory (Lobert, et al , 1990) However the emissions of non-CO_2 greenhouse gases from small-scale combustion devices are not well characterized (Levine , 1990) and are known to be different from open large-scale combustion, such as forest and savannah burning They are also sensitive to changes in combustion conditions (Cooper, 1982, Cofer, et al , 1990). Therefore extensive measurements of emission factors for GHGs from a range of fuels and combustion devices would lead to removing some of the uncertainty in the estimates of total emissions from biomass combustion and also will provide a baseline database to understand the potential for reduction in GHG emissions due to various mitigation measures in the household sector.

A pilot study was conducted in Manila, Philippines to measure the concentrations of a range of GHGs from small-scale cookstoves burning biomass, charcoal, kerosene and liquefied petroleum gas (LPG) (Smith et al., 1992). The results of the Manila study indicate that the emission factors for CH_4, CO, and TNMOC (Total non-methane organic compounds or volatile organic compounds - VOC) from the combustion of wood and charcoal in cookstoves are high In the case of wood combustion, the analysis also revels that, the GHG impact of the four non CO_2 gases - CO, CH_4, N_2O and TNMOC may rival or exceed that from CO_2 itself, an important consideration in setting energy policy (see fig 1).

Based on the experience and results from the Manila pilot study, a more comprehensive study to characterize the emissions of non-CO_2 gases from cookstoves using different solid, liquid and gaseous fuels has been taken up in China and India under a project sponsored to East West Cenre, Hawai by the United States Environmental Protection Agency (USEPA). The present study focuses on 25-30 most common fuel /stove combinations in each nation. Since these countries contain two-thirds of all stoves in developing countries, the stoves in this study represent a large fraction of the combinations in use world-wide (Smith et al, 1996) In this report we describe the methodology and results of the study undertaken in India

CHAPTER 2

Objectives

The focus of this study is on the inventory of green house gases from fuel combustion in cooking stoves used in households. The specific objectives are:

- to collect samples of gaseous emissions from different small-scale combustion devices following a sampling procedure that represents the operating conditions in the field
- to analyze these samples in the laboratory for estimating concentrations of CO_2, CO, CH_4, N_2O, TNMOC and to estimate the emission factors.
- to measure the concentrations of other pollutants such as total suspended particulates (TSP), sulphurdioxide (SO_2) and nitogen dioxide(NO_2) in gaseous emission.
- to measure and estimate thermal parameters such as burn rate and over-all thermal efficiency
- to estimate the annual consumption of different biofuels in different regions of India
- to estimate Green house Gases Inventory for Indian cookstoves

CHAPTER 3

Method for obtaining thermal efficiency & emission factors

Power and thermal efficiency were estimated to check the thermal performance of the stove.

3.1 Thermal efficiency

Thermal efficiency is the product of combustion efficiency and heat transfer efficiency Combustion efficiency measures the extent of which the chemical energy in wood is converted into heat and subsequently used to evaporate water in the vessel Heat transfer efficiency indicates what fraction of the heat produced is actually transferred to the vessel and water The amount of heat used to evaporate water is considered as useful heat input to the vessel since the primary interest is to compare stoves rather than cooking efficiency for any given stock The burn rate and net corrected calorific value of fuel are used in the calculation of thermal efficiency The equation for thermal efficiency calculation is given below

$$\eta(\%) = [(W_i * a * (T_f - T_i) + (W_i - W_f) * L)/(F * t * H_w)] * 100$$

η = efficiency

W_i = Initial weight of water

a = specific heat of water

T_f = Temperature final (°C)

Ti = Temperature initial (°C)

W_i = Initial weight of water (kg)

W_f = Final weight of water (kg)

L = Latent heat of vapourization for water

F = Burnrate (kg/h)

t = Duration (hours)

H_w = Net calorific value of main fuel

3.2 Burn rate

The burn rate is corrected for the amount of kerosene and lighter used, the charcoal remaining and the moisture content of the fuel wood. The burn rates for crop residues and dung cake combustion are similarly calculated by replacing W_w and H_w by their appropriate values for the two fuels The burn rate calculation for kerosene stoves is more straight forward - weight of kerosene consumed divided by experimental time

$$F(kgh^{-1}) = \frac{1}{t}\left[\frac{100 \ x \ W_w}{100+M} + \frac{W_k H_k}{H_w} - \frac{W_c H_c}{H_w}\right]$$

Where

F = Burn rate

t = Duration of the experiment in hours

Ww = Weight of wood (kg)

Wk = Weight of kerosene (kg)

Hk = Calorific value of kerosene (kcal kg^{-1})

Wc = Weight of charcoal (kg)

Hc = Calorific value of charcoal (kcal kg^{-1})

M = Moisture content of wood (%)

Hw = Calorific value of wood (kcal $kg^{-1)}$

3 3 Power

Power refers to the rate at which the energy is used. The power is calculated as follows and expressed in the unit of kilowatt.

Power kW = $F \times H_w \times 1/860$

F = Burn rate

Hw = Calorific value of main fuel

3.4 Emission factors

Our ultimate aim is to estimate the Greenhouse Gas emission inventory for Indian stoves

For example Tg/y of CH_4 = Σ stove fuels (fuel use per year)× emission factor

As a first step the emission factors for Greenhouse Gases from cookstoves has to be estimated. Carbon balance method (Smith *et al.*, 1992) on a carbon basis is used to calculate the emission factors. During combustion the carbon content in the fuel is getting converted to carbonmonoxide (CO), carbondioxide (CO_2), methane (CH_4). Total non-methane organic carbon and some in aerosol and in Ash (AAC)

$$FC = CO + CH_4 + TNMOC + CO_2 + AAC \qquad (1)$$

AAC = carbon in ash, aerosol and char

$$1 = FC/CO_2 - (CO + CH_4 + TNMOC + AAC)/CO_2 \qquad (2)$$

or

$$1 = (FC/CO_2) - K$$

K = is the sum of emission ratio to CO_2

$$(FC) = [(\text{Fuel consumed} \times \%\ \text{of carbon}) + (\text{lighter consumed} \times \%\ \text{carbon}] - [(\text{Char produced} \times \%\ \text{of carbon}) + (\text{ash produced} \times \%\ \text{carbon})] \qquad (3)$$

Emission factor (g/kg dry fuel)

$$CO_2\ \text{as g carbon} = FC/(1+K) \qquad (4)$$

$$CO_2\ \text{as g} = CO_2 = CO_2\ \text{as g carbon} \times 3.67 \qquad (5)$$

Since the molecular weight of CO_2 is 3 67 times heavier than the atomic weight of C

CO as g carbon = (emission ratio for CO) × CO_2 as g carbon . .. . (6)

CO(g) = CO as of carbon× 2 3 . .. . (7)

Since the molecular weight of CO is 2 3 times heavier than the atomic weight of C

CH_4 as g carbon = (emission ratio for CH_4) × CO_2 as g carbon .... (8)

CH_4(g) = CH_4 as of carbon × 1 33 . ... (9)

Since the M W of CH_4 is 1.33 times heavier than the AW of C

emission factor for TNMOC

TNMOC as g carbon = (emission ratio for TNMOC) × CO_2 as g carbon . . ... (10)

TNMOC (g) = TNMOC as g carbon × 1 5 .. . . (11)

N_2O is also one of the the greenhouse gases since there is no carbon in N_2O it is not included in the carbon balance equation but the emission factor can be calculated as

N_2O as g carbon = (emission ratio for N_2O) × CO_2 as g carbon ... . (12)
as of carbon

N_2O (g) = N_2O as g carbon × 3.67 .. .. (13)

Since the MW of N_2O is 3.67 times heavier than the AW of carbon.

The emission factors are calculated for one burn cycle experiment. This has to be con to emission factor g/kg of fuel

(EF for 1 exp / dry fuel consumed (g)) × 1000 = EF g/kg

CHAPTER 4

Experimental Details

4.1 Experimental design

In the present study, solid, liquid and gaseous fuels were examined for their emissions. In solid fuels wood (2 varieties), crop residues (2 varieties), root fuel, charcoal, charbriquette, and dung cakes were tested. The stoves used for solid fuels were traditional mud stove, three rock, improved metal stove with chimney and ceramic with chimney. A local charcoal stove "Angethi" was used for testing charcoal and charbriquettes. Wick type and pressure type stoves were used for kerosene. Commercial LPG stove was used for LPG and a biogas stove was used for biogas. All solid fuels to be tested were procured in one lot, sun-dried and wrapped in plastic sheets to avoid any change in moisture content. Wood fuels were chopped into pieces of same length and width before packing.

Cooking is not a continuous process. The most common cooking practice have different phases for fuel burning rate (power), namely high and low power phase. Unlike gaseous fuels the emission characteristics for solid fuels vary at different times during the burn. Hence it is necessary to choose a burn cycle which is close to the common cooking practice in the field. For the present study the "water boiling test", procedure developed as a standard international method to compare the efficiencies of different stoves (VITA, 1985), was chosen. The water boiling test is a relatively short, simple simulation of common cooking procedure in which a standard quantity of water is used to simulate food. The test includes "high power" and "low power" phases. The high power phase involves heating the standard quantity of water from the ambient temperature to boiling temperature as rapidly as possible. The low power phase follows in which the power is reduced to the lowest level needed to keep the water simmering. This procedure has the added advantage of enabling simulataneous measurement of emissions and efficiency. The burncycle ranged from 30-45 minutes for most fuel stove combinations.

To collect a fairly high portion of the flue gas samples the "Hood method" was adopted. All stoves were placed under a hood built for this purpose and gas samples were collected through a probe placed inside the hood exhaust duct connected to the hood. The hood method (some times called the "direct" method) has been used in studies of unvented cookstoves and kerosene space heaters. (Davidson *et al*., 1986, Lionel *et al*., 1986, Ballard *et al*.,*1996*) Tedlar bags were used to collect the emissions from fire start to fire extinction. To calculate emission factors accurately it is necessary to measure the concentration of gases in the air sorrounding with kitchen So background air samples during the cooking session was collected and analyzed. Parellelly in a second tedlar bag background air during non cooking was also collected sessions and analyzed

After selection of methodology a pilot study has been carried out with wood fuel in a traditional stove to finalize the protocol for burncycle experiment and sample collection. Flue gas and indoor samples were analyzed in TERI and OGIST laboratories The results were compared Main phase experiments were started after satisfactory conclusions were obtained from the pilot phase During the main phase three burncycle experiments were conducted for each stove/fuel combination A total of 29 stove/fuel combinations were tested

4.2. Experimental setup

All experiments were carried out in a simulated rural kitchen (SRK) constructed in the Gual Pahari campus of TERI The design of the kitchen was based on an earlier set up used to test Thermal performance and emission characteristics of cookstoves (Ahuja *et al*., 1987) While the earlier set up used mudwalls and thatched roof The current kitchen is constructed with brick masonry coated with cement and tiled roof The cement coating was given to avoid the resuspension of particles from wall The kitchen has the added advantage that it is located in a rural environment whereas the earlier set up was in urban environment. The mannoverability of ventilation conditions for the present kitchen is similar to that of the earlier set up A detailed description of the simulated rural kitchen is given below.

(a) Description of the Simulated rural kitchen

The kitchen has a volume of $16m^3$ Detailed drawings of the kitchen setup are shown in figures 2, 3 and 4

The size of the kitchen is 8 feet × 8 feet (244cm × 244cm) with the height of the roof being 9 feet (275cm) on one side sloping down to 8 5 feet (259cm) on the other side A 6 5 feet × 3 feet(198cm × 92cm) door was fixed in the south wall for entering the kitchen. There are three windows measuring of size 3ft x 2ft (92cm × 62cm) fitted about above the ground level. There is no window in the wall where the door is fixed There are four rectangular ventilators of size 2ft x 1 ft (61cm × 31cm) fitted in four walls Out of these, two were placed in the bottom one foot above the ground level (BV_1 & BV_2) and the other two (TV_1 & TV_2) were placed in the top (about two and a half feet below the roof) In addition to these rectangular ventilators, five circular ventilators (CV) with a diameter of 9 inches (23 cm) are provided, out of which four were situated about one and a half feet below the roof and one was placed 3 inches (8cm) above the ground level The windows and ventilators were provided primarily to vary the ventilation conditions if desired The entire laboratory was surrounded by an outer boundary wall with floor dimension (457cm × 457cm) of 15 feet × 15 feet and a height of 10 feet (305cm) The function of the outer exclosure is to reduce the wind effects and to keep uniform ventilation conditions in the hut throughout the experiment In the present study all the windows and ventilators and the door fitted in the outer boundary wall were closed during all experiments

A hood arrangement with an adjustable vertical height mechanism was set up on the one side of the kitchen for collection of flue gases Also two wooden platforms of the size of 3 ft x 3ft (92cm × 92cm) were fitted on two walls for keeping flue gas collection bags (Tedlar bags) One platform was fixed near the hood arrangement at a height of 3 5 ft (107cm) from the ground level This was used to keep the tedlar bag and sampler used for flue gas collection Another platform was fixed near the door at a height of 2 ft (61cm) from the ground level This was used to keep the tedlar bag and sampler used for simultaneous collection of indoor background air. These two wooden platforms can be folded up and latched with the help of a locking arrangement provided in the walls.

b) Hood arrangement for stoves without flue

The hood has been designed so that, while not interfering in anyway with the normal combustion of the chulha, it collects a fairly high proportion of the flue gases. Also the sample collected should represent the whole of the combustion gases and not those from one particular point.

A hood consists of a skirt portion, 4"× 4" duct (10cm × 10cm), 6"× 6" (15cm ×15cm) duct and an exit pipe. The skirt portion consists of 2 metal frames made up of 'L' section angles One frame is rectangular in shape with the size of 3 feet × 2 5 feet (91cm × 76cm) Size of another metal frame is 4"× 4"(10cm × 10cm) These two frames were connected to each other by four angles The structure was covered with metal sheet This gave the structure of convergent duct The top portion of the skirt (10cm × 10cm metal frame) was connected to 10cm × 10cm duct which was overlapped by 15cm ×15cm duct in a telescopic arrangement The gap between the two ducts was fitted with glass wool to prevent leakage.
The 15cm ×15cm duct was suitably bent and taken outside the kitchen wall through the circular ventilator fitted on the kitchen wall. This was further connected to the outer wall with 23cm dia circular PVC exit pipe The exit pipe ends on the outer wall and an exhaust fan was fitted at the end in the outer wall

For stoves without flue, 1½ feet (45cm) table was setup to keep the stoves on it and test. Asbestos sheet was placed on the top of the table to withstand the high temperature The height of the hood arrangement was adjusted according to the height of the stove and vessel The hood was fixed in the metal rods fitted in the table with the help of screws The gap between the hood and mouth of the vessel was kept between 1½ to 2 inches (4 -5cm) to read the temperature in the thermometer During the experiment, the exhaust fan was kept on to help the fluegas mix properly A stainless steel probe was placed in the 10cm × 10cm duct of the hood to collect flue gas samples Thermocouple was also set near the probe to measure fluegas temperature at the point of collection Figure 4 show the hood arrangement for stove without flue

(c) Hood arrangement for stove with flue

The hood arrangement was modified to test the stoves with flue (figure. 5). The height of the hood was raised to its maximum level (about 240 cm from the ground level) by reducing the length of the two ducts

The stove with flue was placed on the ground The chimney of the stove end at the hood A probe was placed in 23cm PVC pipe which connect the outer and inner wall During all experiments the exhaust fan was kept on to mix the flue gas properly

4 3 Fuel / Stove tested

a Description of stoves

Traditional mud stove This is a simple 'U' shaped heavy stove for single pot This is made by a local village person with locally available clay and coated with cowdung clay mixture The wall thickness of the stove is about 3 cm The height of the fire box (from the bottom of the stove to bottom of the pot) is about 18 cm This traditional mud stove is found in many parts of India (specially in rural households and economically poor sections live in urban areas) Fuelwood, crop residues and dung cakes are commonly used in this stove Fig 6 shows the diagram of the traditional mud stove

Three rock arrangement Rural people with nomadic tendencies and people who live in pavements with no permanent shelter use to arrange three stoves/bricks for cooking and heating purposes This is a simple open fire cooking arrangement (figure 7) No special skill or investment cost is involved in constructing, operating and maintaining them. This can be easily arranged with stones/bricks. The pot hole size can also be varied by adjusting the stones. Since significant number of population use this arrangement for cooking and heating purposes This was chosen for the study.

To represent the three rock arrangement three bricks (6 cm × 22 cm with the height of 11 cm) were arranged in a star configuration at approximately 120° to one another. The pot hole size was fixed as 190mm diameter to keep 20 cm dia pot The stove can accommodate pots of 18-30 cm in diameter.

Improved unvented stove. This is a portable metallic, non chimney wood stove designed for single pot (figure 8). The stove has been developed in 1983 by Central Power Research Institute (CPRI), Bangalore, India. In 1991, the stove was brought under the Indian standard (IS 13152, 1991) The stove is cylindrically shaped with metal stands The top a circular metal sheet is provided with a hole in the centre and slots A metal grate is provided at the bottom for air flow and to ensure smooth combustion. The stove can accommodate pots of 18-30 cm in diameter The stove is specifically suitable for fuelwood and twigs The stove is commercially available in the name of Priagni and Vishal. So far about 5 million stoves have been disseminated in all parts of the country.

Improved vented I stove This is a two pot cookstove with chimney (Figure 9) A tunnel connects the fire box to the second pot hole and to a chimney. Since two pot holes are provided two things can be cooked on it at the same time with only one fire As smoke goes out of the kitchen through the chimney the chulha becomes `smoke less'

The stove is constructed with sundried prefabricated clay slabs (chapris) The slabs are made with a mixture of good clay and fibrous material such as chopped crop residues Because of this the slab becomes strong and does not crack on drying The stove consists of firebox. two pot holes, connecting tunnel and chimney The height from the fire box floor to the lower edge of the cooking hole is about 18cm The height of the tunnel from the ground level is about 2"

(5 cm) at chimney and fire box ends Whereas in the middle (at second pot hole) the height of the tunnel from the ground level is about 4½"(11 cm) This rise helps in the maximum utilisation of heat to the second pot 3"(8 cm) inner dia cement pipe is used as a chimney Damper is provided between the second pot hole and chimney to control the draft The whole surface of the stove is coated with clay, dung and crop residue mixture. Fuels such as fuel wood. crop residues and dungcakes can be used in this stove The stove is mainly used in rural areas of India

Improved vented 2 stove This is also a two pot cookstove with chimney This is made up of ceramic lining with mud coating this stove was developed at the technical Back-up Unit, Central Glass and Ceramic Research Institute, Khirja, Uttar Pradesh. The stove is same as the improved vented 1 except the four parts such 2 fire boxes, tunnel and coat of the chimney are made up of ceramic The ceramic lining helps in heat retention which help proper combustion This increases the efficiency of the stove Presently the stove is disseminated in the villages of Uttar Pradesh

HARA HARA is a traditionally designed earthern pot for burning dung cakes It is mainly used for slow heating of milk over three to four hours such that, without boiling, the cream of the milk separates as a thick layer at the surface It is also used for cooking fodder It is widely used in villages of Haryana, Uttar Pradesh, Punjab and some parts of rural Rajasthan, Bihar and Madhya Pradesh. There are two designs of the Hara One is the portable type made up of mud clay and crop residue mixture It is quite heavy and the other is fixed in the ground The portable type was chosen for the study Figure 10 shows the diagram of HARA.

Angethi This is a portable bucket type fabricated with GI bucket, mud/concrete and grate. The bucket with the dimension of 23 cm top diameter, 12 cm bottom diameter and the height of 17cm is divided into two halves with grate and the inner wall of the bucket is coated with mud/concrete There is a small opening below the grate/or air vent There are three projections above the bucket to form pot seat. Charcoal, coal and coke are the major fuels burnt in this stove. The fuel has to be fed above the grate in batch operation. For the present study charcoal and char briquettes were tested in this stove. The detailed diagram of the angethi and picture of the stove is given in Figure 11.

Kerosene wick stove For domestic purposes, kerosene is used in wick and pressure stoves. The kerosene wick stove used in the study was developed by Indian Oil Corporation and marketed from 1977 in the brand name of "NUTAN". The weight of the empty stove is about

2.6 kg. The stove consists of fuel tank, burner assembly and load bearing assembly The fuel tank capacity of the stove is 2 litres. The fuel tank is fitted with oil filter cap assembly, a kerosene level indicator (float) to indicate the level of kerosene in the fuel tank and a wick control lever designed for raising/lowering of wick to control the intensity of the flame. The burner assembly consists of 10 wicks, an inner and outer sleeves. The space between the two sleeves are designed to supply more pre-heated air to ensure more combustion An insulated triple wall outer burner casing is provided to minimize the heat wastages At the top of the burner assembly a load bearing assembly (26.5 cm) is placed to provide the platform for vessel. An optional triangular pan support is also provided to place small utensils The stove is used in all parts of India especially in urban areas

Kerosene pressure stove This is a single burner kerosene pressure stove works under a pressure of 100 to 200 $\mathrm{kW_a/m^2}$ The major units of the stove are fuel container, roarer type burner and a top ring The fuel container is made up of brass sheet for the fuel capacity of 2 litre. The fuel container is fitted with a pump, pressure release screw and oil filler cap assembly. The pump is used to the fuel container. The pressure release screw is for the purpose of releasing the container pressure quickly and safely By decreasing the pressure the flame can be adjusted The fuel container is fitted with a socket and a spirit cup The fuel container rests on a metallic legs which is extended up to the top ring The burner assembly consists of a nipple, burner and a flame ring The top ring (21 cm dia) is placed on top of the burner assembly Figure 12 shows the detailed diagram of kerosene pressure stove

LPG stove LPG stoves are commonly used by urban families There are two types of LPG stoves i e with single burner and double burner available for household cooking purposes The stove tested in the present study is with single burner with standards specified by the Indian standards The stove is made up of stainless steel body for use with liquified petroleum gases at 2.452 to 3.432 $\mathrm{kN/m^2}$ pressure A tap is provided in the stove to control the pressure

If the tap is turned "full on" the intensity of the flame is high The intensity can be simmered by turning the tap A detachable metal frame is provided to support the pan. The stove is connected to the gas cylinder with a rubber tubing A detachable regulator is provided at the end of the tube to connect to the cylinder There is a key in the regulator to control the supply of the gas from cylinder to the stove

Biogas stove The biogas stove is used for biogas fuel The stove with 2 burner was used for study But only one burner was operated during the test The burner consist of three row with holes The number and the dimensions (in mm) of the holes in the row are

	PCD	Dia	Nos
Inner row	40	4 7	6
middle row	57	4 7	6
outer row	72	4 7	23

There is a tap in the stove to control the intensity of the flame

Pictures of the stoves tested in this study for solid and liquid fuels are shown in figure 13.

b Fuel description

Solid Fuels

Fuel Wood Wood is extensively used as a fuel in all parts of India. As per the census of India 1991, 61 5% households in India use wood as a major fuel. In rural areas the use as high as 72%. The type of fuelwood and per capita consumption varies from region to region For the present study 2 types of fuel wood *Eucalyptus* (safeda) and *Acacia* (keekar) were tested.

Eucalyptus Eucalyptus trees are largely grown in farm forestry (trees with crops) and in the sides of road and railway lines The forest department of India promotes the growth of *Eucalyptus* tree since it has a good commercial value, easily grown in any area and not browsable by animals. Because of its high calorific value and fibre nature of the fuel it is preferred as a fuel for cooking. *Eucalyptus* trees are mostly growth in punjab, Haryana, Uttar Pradesh, Karnataka and Maharashtra.

Acacia (Keekar) *Acacia* is a small tree grown in any land mainly in barren land and road sides. These trees are common in all parts of India. These trees are mainly used as a fuel. In rural areas the fuel is collected at a zero private cost.

Root fuel (Calligonium Poligonidus) In some parts of Rajasthan state (where the forest cover is less and the soil type is dry) people use root portion of the plant *Calligonium Polligonidus* as a fuel This plant is a fast growing bush type plant The root fuel burns like a fuel wood

Charcoal Charcoal is the product of biomass When the biomass (mainly wood) is burnt in the absence of air (this is usually done slowly in underground or other semi air tight conditions), the volatile content in the biomass will be greatly reduced leaving a solid with about twice the energy density of the wood The resulting product is known as charcoal In India about 3/4 of the charcoal produced is used in small scale industries such as Jwellery making, Laundaries (in traditional ironing machine), silk reeling units and backeries. Only 1/4 th of the charcoal produced is used in the stove (Angethi) for cooking purposes

Char briquette The waste carbon material remained in the gasifier after the biomass gasification is briquetted in to charbriquettes

Dung cakes The other major fuel next to fuelwood is dung cakes This is mainly used in rural areas and among poor groups of urban The dung (cattle waste) is mixed with little crop residues sundried, and used as a fuel Dung cakes are commonly used in all parts of the country except north eastern states In Haryana, UP (upper gangetic region) the use of dung cake as a fuel is maximum (Joshi V, Sinha C S, 1993)

Crop residues Crop residues are the plant materials that are left in the field after extracting the main crop produce Crop residues can be in the form of straw, stalk, husk and fibrous material The type of crop residues as fuel varies as the type of crops grown in the region Mustard stalk, cotton stalk, jute stalk, pulse stalk and paddy straw are some of the crop residues used as a fuel

Pictures of all solid fuels tested in this study are shown in Figure 14

Liquid fuel

Kerosene Kerosene is mainly used in urban areas about 1/4th of the urban population use kerosene as the fuel (1991 census survey data)

Gaseous fuel

Liquid petroleum gas (LPG) and biogas are the two gaseous fuels tested in the study

Liquid Petroleum Gas (LPG) LPG is marketed by Indian Oil Corporation and Bharat Petroleum in the name of "Indane" and "Bharat" in 14 2 kg cylinders

Biogas Biogas is a versatile gas used for cooking and lighting Biogas is a clean, unpolluted gaseous fuel produced mainly from cattle dung and other animal waste The dissemination of biogas plants began in 1981 when through NPBD (National Project on Biogas development) Biogas plants are mainly disseminated in rural areas The potential has to be tapped given the fact that just over 1% of the rural households have been covered so far List of stove fuel combinations tested are given below

Table 1.1 List of stove fuel combinations for gaseous fuel

Fuel	Stove/Burner
LPG	LPG burner
Biogas	Biogas burner

Table 2. List of stove fuel combination for liquid fuel

Fuel	Stove	
	Pressure	Wick
Kerosene	✓	✓

Table 3 List of stove fuel combination of solid fuel

Fuel	Stove						
	Angethi	Traditional mud	Improved unvented	Improved vented 1	Improved vented 2	3 rock	HARA
Charcoal	✓						
Charbriquette	✓						
FuelWood1 (*Eucalyptus*)		✓	✓	✓	✓	✓	
Fuel Wood2 (*Acacia*)		✓	✓	✓	✓	✓	
Root fuel		✓	✓	✓			
CR 1 (mustard stalk)		✓	✓	✓	✓		
CR 2 (Paddy straw)		✓		✓			
Dung cake		✓		✓	✓		✓

4.4 *Sample collection and parameters measured*

In each experiment fluegas and indoor air samples were collected All experiments were conducted under hood arrangement Fluegas sample at isokinetic condition was collected from a probe kept in the hood. Sampling of the gaseous emissions were done with a low volume air sampler at a constant flow rate (about 2 l/min) through a filter and flows into a Tedlar bag Indoor background samples were collected at stove mouth height near the door.

Ambient measurements (outdoor and indoor) were also done during non-cooking hours Ambient outdoor samples were collected at a height of 8 feet.

Time, temperature, weight of water, fuel and char were recorded at the beginning and end of high and low phase. In case of gaseous fuel, volume of gas consumed were recorded during each experiment. Fuel calorific values and moisture content were also measured to calculate overall

efficiency

Fuel, ash and char samples were analyzed for carbon, sulphur, ash and nitrogen contents Flue gas and indoor air samples were analyzed for Carbon dioxide (CO_2), Carbon monoxide (CO), Methane (CH_4) and total non-methane hydrocarbon. Other airborne parameters such as total suspended particulate (TSP), sulphur dioxide (SO_2) and nitrogen dioxides were also measured

One flue gas sample for each stove/fuel combination was filled in 850 ml canister and sent to Oregon Graduate Institute of Science and Technology (OGIST) for gas analysis including N_2O and hydrocarbon speciation Figure 21 shows the filling of canisters from tedlarbag For each fuel, one canister was filled in duplicate through a small ascarite trap (to reduce N_2 artifacts in the canister)

One filter from each stove/fuel combination is analyzed for carbon content

4.5 Measurement technique

a List of Instruments

Instruments . used in this study are listed in table 4.

Table 4. List of instruments

S no	Instrument	Flow rate (l/m)	Make
1	Air sampler		
	- SKC 224 43 X	0-4 0	USA
	- SKC 224 PC XR	0-4 0	USA
	- Gilian	0-4 0	
	- Casella AS 808	0-20	UK
2	Gas Chromatograph AIMIL-NUCON Series 5700		NUCON Engineers, India
3	Spectrophotometer UV-VIS Spectrophotometer 119		Systronics INDIA
4	Bomb Calorimeter		Toshniwal Instruments, India
5	Muffle Furnace		India

b Experimental protocol

Principles involved in the measurement of moisture content, calorific value, total suspended particulates, sulphur dioxide, nitrogen dioxide and GC analysis are given below. The detailed protocol details for each measurement techniques are given in annexure I.

Moisture content (wet basis) Moisture content for solid fuels were determined on the basis of amount of weight loss after drying at 105°c till the weight stabilizes To determine the moisture content of any fuel it is necessary that it should be of small particle size In case of wood fuel, it is sawed in such a way that the whole area, including cell wall, was covered Moreover, to get precise results the experiment was carried out in triplicate About five pieces of the fuel samples taken from different places were sawed and the saw dust obtained were mixed properly and used for moisture content measurement

Known quantity of sample was taken in a crucible and kept in an oven maintained at 105 degrees C The weight loss was measured and the moisture content of the sample was estimated as follows.

$$\%MoistureContent(MC) = \frac{W_i - W_f}{W_i - W_c} \times 100$$

W_i = Initial weight of sample
W_f = Final weight of sample
W_c = weight of crucible

Calorific value Calorific value of a fuel was determined by calorimetry which was based on the principle that amount of heat lost by a body is equal to amount of heat gained This test enables us to compare different fuels in their heat producing capacity Benzoic acid was used to standardize the instrument One gram of sample was taken in a crucible and made into a pallet and the initial weight was noted It was kept in the bomb calorimeter The pressure of oxygen was maintained at a constant level The pressure was allowed to rise up to 18 atmosphere Measured quantity of water was taken in the vessel and placed in the calorimeter The ignition circuit was connected and the temperature in a Beckham thermometer was noted After ignition the temperature raise in every minute till a constant temperature attained was recorded The pressure was released and the length of unburnt fuse wire was measured The calorific value was calculated as

$$\frac{(t_c \times w) - (m + n)}{weightofsample(g)} = kcal/kg$$

where

t_c	-	corrected temperature rise (°C)
w	-	apparent heat capacity by benzoic acid (cal)
m	-	correction for thread (cal)
n	-	correction for nicrome ignition wire (cal)

TSP Measurement Quartz fiber filters of 37mm diameter (Pallflex products Co., Putnam, CT, USA) were used for Total Suspended Particulate (TSP) measurements. The flow rate of the sampling pump was adjusted to fill 80 liter Tedlar bag throughout a burn cycle. The flow pumps were calibrated before and after measurements using the soap bubble method TSP was calculated from the filter weight difference and volume of air sampled.

Quartz fiber filters were conditioned by heating at 800°C for 2 hours and then placed in a desiccator for at least 24 hours before weighing. The filters were carefully placed in the filter holders and used for sample collection After sampling, the filters were taken out of the holder and placed in a petri dish, desiccated for 24 hours and weighed. The net increase in the weight of the filter after sampling was calculated for total suspended particulates. One filter from each stove/fuel combination was analyzed for carbon content.

Sulphur dioxide West and Gake method (BIS 1970) was followed to estimate Sulphur dioxide in fluegas and indoor background samples The air samples were bubbled through the absorbing media containing sodium or potassium tetrachloro mercurate at a constant flow rate (1.5-2 0 l/m) during the entire burncycle experiment Non volatile dichloro sulphito mercurate ion formed in this process was reacted with acid bleached para rosaniline and formaldehyde to form a complex ion which absorbance was read spectrophotometrically at 550nm. The corresponding SO_2 concentration was measured by comparing the absorbance with standard graph developed with known concentrations of SO_2.

Nitrogen oxides Nitrogen oxides were measured as nitrogen dioxide by modified Jacob & Hochhier method (BIS 1975) Fluegas and indoor background samples were bubbled through an absorbing media containing sodium hydroxide - sodium arsenite solution to form a stable solution of sodium nitrate The nitrate ion produced during sampling was reacted with phosphoric acid, sulphanilamide and N-(1-napthyl)-ethylenediamine dihydrochloride to form an azodye The absorbance of the azodye was read in spectrophotometer and the corresponding concentration was estimated using a standard graph made with known NO_2 concentration

GC analysis Flue gas and Indoor air samples collected in tedlar bags were analyzed for CO, CO_2, CH_4 and THCs. A system of GC/FID/methanizer method was used to analyze CO_2, CO and CH_4 . In this system, a carbonshere packed column was used to separate CO, CO2 and CH_4 A blank column was used to measure THC TNMHC was measured indirectly by subtracting CH_4 from the THC

4.6 *Quality control plan (QCP)*

Efforts were made carefully to maintain the quality following a Quality Control Plan

- Biomass fuels were collected in one lot, sun-dried and covered with plastic sheet to avoid any change in moisture. Dungcakes used in all stove-fuel combinations were made by the same person by same ratio of dung and crop residue mixture
- For each stove-fuel combinations mock experiments were conducted to standardize the burn cycle and minimize the natural variability due to differences in operator behavior.
- After each burn cycle experiment, the doors and windows were opened. Exhaust fan and side fans were switched on to clean the room properly
- Char, ash remaining in each experiment were covered with aluminum foil, labeled for further carbon analysis.
- Tedlar bags and teflon tubings used in each experiment were flushed adequately with compressed air to clean it properly
- Tedlar bags and teflon tubings used for low grade fuels such as solid biomass fuels were not used again
- After each stove-fuel combination the probe and the hood were cleaned with vacuum cleaner.
- The Gas Chromatograph instrument the probe and the hood were cleaned with vacuum cleaner
- Leak proof tested and certified canisters were filled with fluegas and sent to OGIST for further analysis of gaseous emissions. After receiving the results from OGIST the values were compared with TERI values and in case there were many deviations, the experiments were repeated
- The pumps used for collection of aerosol samples were calibrated before and after each experiment
- Filters used for TSP measurements were weighed for at least twice If the difference was more than 0.005 milligram in the two weighing, the balance was calibrated and weighed again
- Blank filters were weighed and treated in the same fashion approximately 1 blank for 20 samples were used.
- After post weighing, the filter cassettes were sealed properly for further carbon content analysis.
- Spectrophotometer used for SO_2 and NO_2 analysis was calibrated carefully and checked with standards after each set of analysis.

CHAPTER 5

Results and Discussion

In the present study we have tested 29 stove fuel combinations In each stove fuel combination we conducted three experiments. For each experiment thermal performance parameters such as thermal efficiency and power were calculated. Fuels were analysed for carbon, nitrogen, sulphur, ash, hydrogen and calorific value. Concentration of GHGs such as CO2, CO, CH4 in flue gas and indoor samples were analyzed for each experiments OGIST analyzed other gases such as TNMOC and N2O Besides the GHGs we also analyzed other pollutants such as TSP, SO2 and NO2 The net concentration of GHGs, fuel carbon and carbon content in particulate were used to estimate the emission factor for GHGs We also estimated the anual fuel use (different fuels used in different parts of India) for the year 1991 From the fuel estimates and emission factors for different fuels, we have achieved our ultimate goal of estimating Greenhouse Gas inventory for small combustion devices in India In the results and discussion, the concentration of pollutants in fluegas and indoor samples for three experiments were averaged and given. Fuel, ash/Char analyses were averaged and given Besides these tables we present the results received from OGIST We compared the OGIST values with TERI values and corrected accordingly using regression analysis The corrected values were used for estimating the emission factors and GHG emission inventory

5 1 Fuel, Ash/Char analysis, thermal performance and concentration of pollutants in flue gas and indoor samples

We have tested 11 fuels that are broadly classified into gaseous, liquid and solid fuels All solid fuels and the liquid fuel kerosene were analyzed for calorific value, carbon, ash, sulphur, nitrogen and hydrogen content. Moisture contents for all solid fuels were also estimated. For Biogas the carbon and hydrogen content were estimated from the gas analysis For LPG the calorific value was given by “BHARAT petroleum ” The chemical composition, moisture content and net (low)calorific value of the fuels tested were given in the table 5.

Table 5 Chemical composition, moisture content and net calorific value of various kinds of fuels

Fuel	Moisture content %	Net Cal Value Kcal/Kg	%				
			Carbon	Nitrogen	Ash	H_2	Sulphur
LPG	-	10,950	86				
Biogas	-	4230 kcal/NM^3	39 6			6 5	
Kerosene	-	10300	84 3	0 02	0 0	14 2	0 04
FW I (Eucalyptus)	6 1	3663	45 4	0 14	0 4	6 4	0 02
FW II (Acacia)	6 5	3607	41 8	0 35	2 89	6 3	0 01
Root fuel	5 7	3698	51 8	1 18	7 0	4 5	0 08
Charcoal	1 7	6143	80 0	0 69	7 4	1 8	0 06
Char briquette	7 2	3805	50 3	0 25	40 0	3 2	0 05
CR I (mustard straw)	5 9	3949	42 1	0 36	2 7	6 3	0 01
CR II (paddy straw)	8 8	3112	38 1	0 40	15 6	6 2	0 05
Dung cake	7 3	2810	33 4	0 90	52 2	3 9	0 07

The average moisture content for different solid fuels varies from 1 7 to 8 8% The moisture content is low for charcoal and high for crop residue II (paddy straw) Net calorific value for wood, root, char briquette and crop residues are between 3000 - 4000 kcal/kg For dung cake the average net calorific value is lower than 3000 kcal/kg Among solid fuels charcoal is recorded with high net calorific value (above 6000 kcal/kg). The carbon content for solid fuels varies from 33 to 80 percent Dung cakes have low carbon content, low net calorific value and high ash content Ash content of 52% for dung cakes is higher than the earlier reported ash content of about 15-20% and 31% (Smith1987, Salaria 1983) The ash content in dungcake and char briquettes are much higher than wood and root This may be due to the presence of more dirt particles in these fuels The ash content of paddy straw is close to the reported value of 15 5 % (Salaria 1983).

Power and thermal efficiency

Thermal performance such as power input and thermal efficiency of various stove fuel combinations tested were calculated according to the methodology described earlier We did not attempt to change the power amongst different experiments except some interventions in the fire only to ensure steady flame The power input and efficiency values for three experiments in each stove fuel combinations were averaged and the average values are given in the table 6, 7 & 8.

Table 6 Power input and thermal efficiency for gaseous fuels

Fuel/stove	Power kW	Efficiency %
LPG	1.6 ± (0.1)	53.6 ± (2.2)
Biogas	1.4 ± (0.1)	57.3 ± (0.5)

Table7 Power input and thermal efficiency for liquid fuel

Fuel/stove	Power kW	Efficiency %
Kerosene/wick	1.3 ± (0.1)	50.0 ± (6.7)
Kerosene/pressure	1.7 ± (0.1)	47.0 ± (2.2)

Table 8 Power input and thermal efficiency For Solid Fuels

Fuel/stove	Power kW	Efficiency %
CCI/Angethi	2.6 ± (0.2)	17.5 ± (2.7)
CB/Angethi	1.6 ± (0.3)	16.4 ± (0.5)
FW1/TM	4.1 ± (0.0)	16.7 ± (0.7)
FW1/3 rock	4.6 ± (0.1)	17.7 ± (0.3)
FW1/im uv	3.5 ± (0.3)	21.4 ± (1.8)
FW1/im V_1	3.9 ± (0.5)	22.0 ± (1.8)
FW1/im V_2	2.5 ± (0.1)	28.7 ± (1.0)
FW2/TM	4.1 ± (0.2)	18.2 ± (0.6)
FW2/3 rock	2.9 ± (0.2)	18.1 ± (0.6)
FW2/im uv	2.4 ± (0.6)	25.7 ± (2.5)
FW2/im V_1	3.1 ± (0.2)	23.5 ± (2.2)
FW2/im V_2	2.5 ± (0.2)	29.0 ± (1.9)
RFI/TM	4.7 ± (0.9)	14.2 ± (1.8)
RF/im uv	3.4 ± (0.5)	22.8 ± (1.2)
RF/imV_1	2.8 ± (0.5)	19.7 ± (1.3)
CR1/TM	7.6 ± (1.0)	12.4 ± (1.0)
CR1/im uv	5.8 ± (0.2)	21.7 ± (1.6)
CR1/im V_1	6.1 ± (1.2)	13.5 ± (0.5)
CR1/im V_2	4.9 ± (0.4)	18.5 ± (0.8)
CR2/TM	6.6 ± (0.2)	9.8 ± (1.1)
CR2/im V_1	4.8 ± (0.4)	10.9 ± (1.0)
DC/TM	4.1 ± (0.5)	9.4 ± (0.6)
DC/Hara	6.4 ± (0.6)	8.2 ± (1.3)
DC/im V_1	3.9 ± (0.1)	10.0 ± (0.2)
DC/im V_2	4.0 ± (0.1)	12.8 ± (1.0)

The above three tables show that the power input of the stoves tested ranged from 1.3 kW for kerosene wick stove to 7.6 kW for Crop residue I (mustard stalk) in traditional stove. The average power input for the stoves burning gaseous and liquid fuels were low (Ranged between 1.3- 1.7 kW). For solid fuels the power input values varied from 1.6 for char briquettes in angethi to 7.6 for mustard stalks in traditional stove. When we compared with the improved stoves, the traditional stove had high power in all of the fuel categories. Among various fuels tested the power input increases from gaseous fuel and kerosene to wood, and charcoal to dung cake to cropresidues (Figure 15)

Thermal efficiency

The average thermal efficiency of the Biogas stove (57.3%) is the highest among all stoves tested. Khadi and village Industries Commission (KVIC) and Bureau of Indian Standards (BIS) recommends that the efficiency of domestic biogas burner should not be less than 55% A report of KVIC states that a thermal efficiency of 59 5% could be obtained for the corresponding power of 1 61kW (Kishore and Dinghra 1990) We got the average efficiency of 57.3 for the corresponding power of 1 59 kw The average efficiency of LPG stove is 53.6% that is less than the BIS specification of 60% (IS 4246-1984) The kerosene wick stove had the efficiency of 50% and the average efficiency of kerosene pressure stove was 47%. The efficiency of the kerosene stove wick stove is less than the efficiency of 57% reported (TERI 1987).

In angethi charcoal and charbriquette were used The efficiency of Angethi (17 5%) when charcoal was used as the fuel is comparable to the efficiency of angethi (15.3%) quoted by Wazir S. 1981 We tested six biofuel burning stoves (traditional, Hara, 3 rocks, improved un vented, improved vented1 and improved vented2) Average efficiency of traditional stove with various biofuels tested varied from 9 4 to 18 2% The efficiency of traditional stove was low for dung cake and high for Fuel wood1 Wazir S, 1981 reported the efficiency of the traditional stove vary from 5-20% The efficiencies obtained in this study is within the range given by wazir S (1981) George (1997) also quoted the efficiency of traditional rural chulha as 17 9 that is also comparable to the efficiency of traditional chulha when tested for wood. The two wood species were also tested in 3 rocks stove The average efficiency of the 3 rocks stove was about 18% which is in the efficiency range (12-24%) of three rock stove quoted by TERI

Three improved stoves were tested The efficiencies of the improved stoves were higher than that of the traditional and three rock stove Among the three improved stoves, the improved V2 had high efficiency for all fuels except crop residue1 The higher efficiency for the improved v2 may be due to the ceramic parts that help in heat retention The average efficiencies of the improved V1 stove with various fuels vary from 10-23 5% A study conducted by R C Pal and Veena Joshi (1989) reported the efficiency of the improved V1 (Nada chulha) varied between 10 8% and 19 6%. The range is comparable to the values obtained in the present study The efficiency of the improved unvented stove varied from 21-26% FAO (1993) reported the efficiency of "Priyagni" (improved unvented stove) for the wood fuel as 26% When we tested wood fuels in the improved unvented stove, we also got the similar average efficiency (21.4 & 25.7). Among various fuels, dung cake had low efficiency in all stoves Lowest efficiency was observed for dung cake in hara Figure 16 shows that the efficiency of different stoves for different fuels This shows that one move up from dung cake to cropresidue to wood to kerosene to gas in the energy ladder the efficiencies also increase This is similar to the typical energy ladder of south Asia discussed by smith et al (1994)

The average overall efficiency of each stove fuel combinations is found to decrease with increasing average power levels The relationship is nonlinear (Figure 17). Biogas, LPG and Kerosene stoves burnt at low power and with high efficiencies where as dungcake and crop residues burnt at high power with low efficiencies

The net TSP concentrations (flue gas- indoor) for various fuel/stove tested were given in the table 9 The TSP concentration was found low for gaseous fuels (Biogas and LPG) and high for crop residues The increases in the TSP concentration for various fuel/stove were Biogas-LPG-Kerosene-Charcoal-Rootfuel-dung cake-wood- cropresidues

Table 9 Concentration of TSP and carbon content in TSP

Fuel/stove	TSP (mg/m^3)	carbon content (mg/m^3)
LPG	0 32 ± (0 14)	0 32 ± (0 14)
Biogas	0 25 ± (0 21)	0 12 ± (0 09)
Kerosene/wick	0 46 ± (0 32)	0 41 ± (0 24)
Kerosene/pressure	0 48 ± (0 05)	0 48 ± (0 05)
CC/angethi	1 35 ± (0 49)	1 27 ± (0 49)
CB/angethi	2 87 ± (0 36)	2 18 + (1 00)
FW1/tm	2 84 ± (0 13)	2 84 ± (0 13)
FW1/3 rock	3 62 ± (0 58)	3 62 ± (0 58)
FW1l/im uv	3 37 ± (0 59)	2 83 ± (0 21)
FW1/im v1	4 34 ± (0 38)	3 99 ± (0 99)
FW1/im v2	3 15 ± (0 57)	3 15 ± (0 57)
FW2/tm	3 09 ± (0 17)	2 54 ± (0 80)
FW2/3 rock	2 96 ± (0 67)	2 83 ± (0 81)
FW2/im uv	3 52 ± (1 05)	3 52 ± (1 05)
FW2/im v1	4 32 ± (0 64)	4 32 ± (0 64)
FW2/im v2	4 66 ± (0 17)	4 66 ± (0 17)
RF/tm	2 32 ± (1 49)	2 32 ± (1 49)
RF/im uv	2 94 ± (0 58)	2 88 ± (0 61)
RF/im v1	2 02 ± (0 88)	1 64 ± (0 76)
CR1/tm	3 24 ± (0 10)	3 54 ± (0 10)
CR1/im uv	4 04 ± (0 85)	4 04 + (0 85)
CR1/im v1	5 74 ± (1 37)	5 74 ± (1 37)
CR1/im v2	6 69 ± (0 26)	6 69 ± (0 26)
CR2/tm	5 25 ± (0 79)	5 25 ± (0 79)
CR 2/im v1	6 02 ± (1 17)	6 02 ± (1 17)
DC/tm	4 05 ± (0 66)	2 99 ± (0 78)
DC/hara	2 38 ± (0 16)	2 38 ± (0 16)
DC/im v1	3 77 ± (0 26)	3 77 ± (0 26)
DC/im v2	4 35 ± (0 25)	4 35 ± (0 25)

Note

TSP levels are net concentration (fluegas-Indoor)

The carbon content value greater than the TSP value was considered as 100% carbon

The results of GC analysis are given in the Table 10, 11 & 12. In Table 10 the average concentration of CO, CO_2 & CH_4 in fluegas and indoor samples analyzed by TERI laboratory is given In OGIST laboratory among the fluegas samples of three experiments, one was analysed for CO, CO_2, CH_4 and TNMOC. For each fuel, one fluegas samples for one fuel was also analyzed for N_2O concentration. The result given by OGIST laboratory is shown in Table 11. OGIST results were compared with the particular experiment values analyzed by TERI. Among 29 fuel/stove combinations, canisters for seven stove fuel combinations were opened on the way. So no OGIST values for seven fuel/stove combinations. During the pilot phase experiments (FW1/tm) due to improper conditioning of the column the CO_2 calibration was not stabilized. So TERI values for the pilot phase experiments were not considered for comparison. Due to the GC problem during the experiments with CR2/tm and cowdung/imv1 TERI values for those experiments were not reliable for comparison. For rest of the experiments TERI values were compared with OGIST results and given in Table 12.

Table 10 Concentrations of CO2, CO and CH_4 in ppm in fluegas and indoor background air (analyzed in TERI Laboratory)

Fuel/stove	CO2		CO		CH4	
	flue gas	indoor	flue gas	indoor	flue gas	indoor
LPG	2249±(465)	779±(24)	15±(5.0)	bdl	1.6±(0.3)	1.2±(0.1)
Biogas	1509±(636)	404±(77)	2.7±(1.9)	bdl	3.3±(1.3)	3.8±(0.8)
Kero wick	2789±(303)	665±(93)	26.1±(6.7)	bdl	2.3±(0.3)	1.2±(0.5)
Kero/pressure	2149±(267)	518±(114)	73±(21)	bdl	3.7±(0.8)	1.8±(0.2)
CC/angethi	1566±(241)	349±(91)	327±(86)	17.0±(11.8)	15.7±(6.2)	3.1±(0.5)
CB/angethi	2622±(736)	459±(79)	375.8±(128)	31.0±(17.8)	28.0±(21.2)	3.6±(1.4)
FW1I/3 rock	5824±(231)	419±(26)	250.1±(38)	9.0±(3.5)	27.4±(9.6)	2.6±(0.4)
FW1I/im uv	2020±(655)	412±(100)	111.0±(62)	3.9±(1.8)	15.0±(9.1)	
FW1I/im v1	1722±(400)	510±(18)	322.4±(23)	22.8±(4.3)	54.8±(11.0)	4.9±(0.3)
FW1/im v2	2293±(913)	577±(115)	134.7±(4.0)	8.0±(4.8)	22.2±(15.0)	2.9±(1.2)
FW2/tm	4306±(515)	557±(79)	182.8±(51)	7.3±(4.4)	35.0±(14.9)	3.4±(0.2)
FW2/3 rock	1897±(213)	469±(10)	82.2±(8.9)	13.2±(2.6)	39.4±(9.9)	4.1±(1.4)
FW2/im uv	1330±(175)	466±(33)	50.7±(13.4)	1.5±(2.5)	10.0±(3.0)	2.2±(0.3)
FW2/im v1	1603± (125)	552±(15)	220.1±(14)	22.4±(3.0)	47±(10.9)	7.3±(2.0)
FW2/im v2	1563±(170)	525±(60)	45.9±(17.8)	5.3±(1.3)	9.2±(0.6)	2.9±(1.3)
RF tm	3801±(445)	553±(30)	148.1±(86)	7.8±(1.2)	77.3±(64.1)	2.5±(0.4)
RF/im uv	4289±(128)	392±(51)	284±(146)	6.3±(7.3)	25.3±(13.2)	1.9±(0.3)
RF im v1	1124±(83)	516±(54)	45.5±(10.6)	9.5±(3.2)	6.9±(2.1)	3.0±(0.2)
CR 1/tm	6165±(646)	418±(51)	613.4±(153)	16.4±(0.3)	105.7±(44)	3.1±(1.5)
CR 1/im uv	3107±(230)	800±(794)	238.1±(240)			

Fuel/stove	CO2		CO		CH4	
	flue gas	indoor	flue gas	indoor	flue gas	indoor
CR1/im v1	1860±(279)	567±(38)	271.6±(105)	25.3±(10)	92.3±(33.2)	5.8±(1.3)
CR 1/im v2	2257±(699)	658±(63)	164.8±(38)	13.2±(3.1)	22.1±(5.6)	3.5±(0.4)
CR 2 / tm	6251±(834)	583±(39)	542.5±(165)	17.5±(3.8)	84.3±(39.0)	3.0±(0.3)
CR 2/im v1	1123±(631)	530±(50)	129±(94)	17.5±(8.9)	15.5±(9.8)	8.3±(8.9)
DC/tm	2048±(131)	564±(35)	158.8±(14)	7.5±(5.0)	28.5±(5.2)	3.2±(0.8)
DC/hara	3677±(389)	333±(47)	456.6±(155)	5.8±(4.2)	206.1±(245)	2.4±(0.2)
DC/im v1	2312±(313)	372±(63)	136±(18.3)	22.4±(4.7)	24.3±(7.4)	6.9±(0.2)
DC/im v2	2181±(368)	389±(53)	132.1±(19)	22.7±(6.4)	23.1±(7.4)	5.2±(1.2)

Table 11 Concenrations of CO_2, CO, CH_4 & TNMOC and N_2O in ppm in Fluegas samples (analysed by OGIST)

Fuel/stove	CO_2	CO	CH_4	tnmoc	N_2O
LPG	874	8	2	11	0 362
Biogas	1435	1	3	0	0 354
Kerosene/pressure	1355	47	3	6	0 354
CC/angethi	1576	192	9	6	
CB/angethi	2902	318	26	25	
FW1/tm ex1	3870	163	2	42	0 649
FW1/tm ex2	4310	149	2	45	0 392
FW1/tm ex3	3762	182	27	55	0 735
FW1/3 rock	3300	112	17	24	0 447
FW1/im uv	2131	102	16	21	0 454
FW1l/im v1				canister opened on the way	
FW1/im v2				canister opened on the way	
FW2/tm	3314	139	25	27	
FW2l/3 rock	1254	73	13	14	0 588
FW2/im uv	9939	47	10	8	0 388
FW2/im v1	1174	2	22		
FW2/im v2	690	15	5		
RF/tm				canister opened on the way	
RF/im uv				canister opened on the way	
RF/im v1	984	20	5		
CR1/tm	5461	340	10	13	0 468
CR1/im uv				canister opened on the way	
CR 1/im v1	1583	150	35		
CR 1/im v2	1333	80	14		
CR 2/tm	3408	329	36	58	
CR2/im v1	744	43	8		
DC/tm	1556	146	23	33	
DC/hara				canister opened on the way	
DC/im v1	6386	35	9		
DC/im v2	1127	85	18		

Table12 Comparison of CO_2,CO, & CH_4 concentrations analyzed by TERI with OGIST results

Fuel/stove	CO_2		CO		CH_4	
	TERI	OGIST	TERI	OGIST	TERI	OGIST
Biogas	1960	1435	1.2	0.7	2.5	3.1
LPG	2116	874	16.6	8.1	1.9	2.1
Kero/pressure	1911	1355	71.8	47.0	3.4	3.2
CC/angethi	1304	1576	290.6	191.9	10.6	8.5
CB/angethi	3458	2902	522.3	317.5	52.5	25.6
Fw1/3rock	5794	3300	214.2	111.9	22.1	17.2
Fw1/imuv	1829	2131	112.5	101.5	18.1	16.0
Fw2/tm	4175	3314	178	139	26.8	24.5
Fw2/3rock	1785	1254	82.7	72.6	45.6	13.3
Fw2/imuv	1380	993	56.1	47.2	10.7	9.7
Fw2/imv1	1458	1174	210	91.8	35	22.2
Fw2/imv2	1722	690	66	15.4	10.0	4.9
RF/imv1	1220	984	57.6	20.1	9.2	5.4
CR1/tm	6716	5461	655	340	142	106
CR1/imv1	1918	1583	314	150	68.5	35.4
CR1/imv2	2996	1333	173	79.8	20.4	13.9
CR2/tm	6772	3408	392.7	328.8	43.5	35.6
DC/tm	1995	1556	166.8	145.8	32.8	22.9
DC/imv2	2352	1127	116.7	85.1	18.3	18.1

For carbondioxide, carbonmonoxide and methane the Teri values were plotted against OGIST values and we did the regression analysis for these pollutants Figures 18, 19 & 20 show the regression analysis for CO_2,CO & CH_4 The R^2 values for the three regression analysis were above 0.80. Using x variable(m) and intercept(c), Teri CO_2,CO,CH_4 values for each experiments were corrected and the corrected values were used for emission factor calculation.

The net concentrations (fluegas minus indoor) of SO_2 and Nox (measured as NO_2) for the fuel/stove tested are given in the table 13 The table reveals that for SO2, the difference between fluegas and indoor is marginal (less than 1ppb) for LPG, Biogas, Charcoal and Charbriquette. For cropresidues the average net concentrations of SO2 vary from 0.7 to2.9ppb in different stoves. For wood fuels the range for SO2 concentration is 1.2 to 6.3ppb and for dungcakes the value range from 0.3 to 6.3ppb.

Among the various fuel/stove tested, the net NO_2 concentration is high for LPG(11ppb) For wood fuels the net NO2 concentration vary from 1 to 4ppb For cropresidues and dungcakes the net NO2 concentration didnot exceed 5ppb The low NO2 emission for biofuel is due to the low level of fuel nitrogen in biofuel (see table 5)

Table 13 Net concentration of SO_2 & NO_x concentration (in ppb)

Fuel/stove	SO_2	NO_x
LPG	0 7±(0 3)	11 0±(3 5)
Biogas	0 7+(0 6)	2 0±(0 6)
Kerosene/wick	1 3±(0 6)	1 0±(0 8)
Kerosene/pressure	2 0±(1 0)	2 0±(0 2)
CC/angethi	0 9±(0 6)	7 0±(3 6)
CB/angethi	0 2±(0 1)	10±(2 5)
FW1 l/tm	2 1±(0 6)	1 8±(0 5)
FW1/3 rock	1 1±(0 1)	1 0±(0 6)
FW1/im uv	1 3±(0 6)	3 0±(2 0)
FW1/im v1	3 7±(0 5)	3 0±(1 5)
FW1/im v2	1 4±(1 0)	4 0±(1 9)
FW2/tm	1 7±(0 6)	2 0±(1 0)
FW2/3 rock	1 2±(0 3)	4 0±(2 5)
FW2/im uv	1 7±(0 6)	1 0±(0 6)
FW2/im v1	6 3±(1 0)	4 0±(2 2)
FW2/im v2	1 4±(1 0)	4 0±(1 9)
RF/tm	1 0±(0)	2 0±(0 6)
RF/im uv	0 7±(0 3)	1 0±(0 5)
RF/im v1	0 7±(0 2)	3 0±(1 3)
CR1/tm	1 3±(0 6)	3 0±(2 0)
CR1/ im uv	1 7±(1 1)	3 0±(1 1)
CR 1/im v1	2 2±(1 2)	5 0±(2 9)
CR 1/im v2	2 9±(0 5)	5 0±(1 1)
CR 2/tm	0 7±(0 3)	2 0±(0 8)
CR 2/im v1	1 9±(0 7)	2 0±(1 0)
DC/tm	0 3±(0 2)	1 0±(0 5)
DC/hara	0 7±(0 3)	1 0±(0 8)
DC/im v1	4 1±(1 5)	2 0±(0 5)
DC/im v2	4 2±(1 0)	2 0±(0 7)

Note

SO_2 and NO_x values are net concentrations (fluegas - indoor)

In thermal perfomance calculation we considered the amount of charcoal/char left and the net calorific value of charcoal/char. For this reason the we analysed charcoal/char sample of all solid fuels for net calorific value In carbon balance equation which was used to estimate the emission factor, the carbon content in Ash and aerosol was also considered So charcoal, ash and char samples were analysed for its ultimate composition The ash and char analysis results are given in the table 14

Table 14 Net calorotic value and composition(in %) of Ash and char samples of various solid fuels

fuel	ash/char	Net calorific value(kcal/kg)	carbon	nitrogen	ash	hydrogen	sulphur
char coal	ash	1698	21 1	0 09	69 0	1 81	0 41
char briquette	ash	396	8 7	0 36	89 3	0 7	0 14
Fuel wood1	ash	2298	61 0	1 0	22 6	5 3	0 23
Fuel wood1	char coal	7089	80 9	0 79	2 2	6 5	0 02
Fuel wood2	ash	977	6 1	0 37	88 2	0 6	0 04
Fuel wood2	char coal	6510	80 3	0 85	7 9	5 3	0 07
Root fuel	ash	938	14 1	0 21	80 1	1 2	0 21
Root fuel	char coal	5712	54 3	0 6	31 2	4 3	0 98
Crop residue1	char	1789	24 4	1 1	64 8	2 1	0 65
Cropresidue2	char	803	23 5	0 3	71 2	2 0	0 06
dung cake	ash	181	2 9	0 4	94 7	0 3	0 08

5 2 Emission Factor Estimation

Emission factors for greenhouse gases suchas CO2,CO,CH4,TNMOC and N2O were calculated based on the carbon balance method (described earlier). In the emission factor calculation, concentration of CO2,CO,CH4 in fluegas and indoor samples (analysed byTeri) for all experiments were corrected and used Emission factors were estimated for all three experiments in each fuel/stove combination As the first step net concentration of CO2,CO & CH4 were estimted by subtracting the indoor concentration from concentrations in fluegas The concentrations of GHGs in fluegas, indoor and net concentrations (fluegas-indoor) for three experiments in varios stove/fuel combinations are given in Table 15.

From the net concentration of GHGs emission ratios and emission factors were estimated and given in the Table 16

Table 15 Corrected concentration (in ppm) of various GHGs in the fluegas indoor and net values for different fuel/stove combinations

stove/fuel	CO2(t)c	co2(I)c	CO2(N)	CO(t)c	CO(I)c	CO(N)	CH4(t)c	CH4(I)c	CH4(N)	TNMOC	aac
biogas biogas	1283	249	1034	9	7	2	2.0	1.6	0.4	0.4	0.4
	570	358	212	7	7	1	1.6	0.5	1.1	0.4	0.3
	1407	298	1109	8	7	1	0.7	0.5	0.2	0.4	0.0
DC hara	2824	285	2539	342	8	334	311.8	0.4	311.3	140.0	4.6
	2743	252	2491	186	7	179	32.2	0.3	31.9	116.0	4.7
	2310	218	2092	218	11	207	47.9	0.5	47.3	154.0	5.2
DC inv 2	1741	333	1408	73	21	52	13.2	2.8	10.4	92.0	8.8
	1685	260	1425	69	15	54	10.6	1.4	9.2	92.0	8.4
	1263	280	984	89	20	68	17.1	2.6	14.5	92.0	9.4
DC/inv 1	1811	249	1562	77	20	57	14.0	3.2	10.8	92.0	7.9
	1757	331	1426	70	16	55	9.9	3.4	6.5	92.0	7.1
	1402	258	1145	89	20	69	19.3	3.3	16.0	92.0	8.0
DC/tm	1402	430	972	82	13	69	13.4	1.0	12.5	47.0	6.8
	1432	387	1044	95	8	87	19.9	0.4	19.5	47.0	4.3
	1575	430	1145	95	11	84	18.0	1.4	16.6	47.0	7.2
CB/angethi	1486	291	1195	177	16	161	9.4	0.4	8.9	36.0	6.2
	2470	402	2069	283	34	250	32.4	2.2	30.2	36.0	2.2
	1673	331	1343	157	19	138	8.5	1.0	7.5	36.0	5.0
CC/Angethi	1162	202	960	202	13	189	13.3	1.1	12.3	9.0	3.1
	941	255	686	161	23	138	5.7	1.0	4.7	9.0	3.3
	1278	330	948	147	12	136	7.7	0.5	7.2	9.0	1.4
kero pressure	1746	308	1438	57	7	50	1.8	0.1	1.7	18.0	0.9
	1505	470	1036	34	7	28	0.8	0.1	0.8	18.0	1.1
	1372	372	1000	45	7	38	1.1	0.0	1.1	18.0	1.0
kero wick	1936	455	1481	17	7	10	0.2	0.0	0.2	18.0	1.3
	1816	444	1372	22	7	15	0.6	0.0	0.6	18.0	0.4
	2235	563	1671	23	7	17	0.4	0.0	0.4	18.0	0.8
lpg	1339	549	790	12	7	5	0.0	0.0	0.0	14.7	0.5
	1517	575	942	15	7	9	0.1	0.0	0.1	14.7	0.5
	1979	580	1399	17	7	10	0.0	0.0	0.0	14.7	1.0

stove/fuel	CO2(t)c	co2(l)c	CO2(N)	CO(t)c	CO(l)c	CO(N)	CH4(t)c	CH4(l)c	CH4(N)	TNMOC	dac
CR1/imv2	2142	431	1711	98	12	86	11 9	0 8	11 1	57 0	14 2
	1156	510	645	72	15	57	10 1	1 1	9 0	57 0	13 2
	1556	506	1050	112	15	97	17 0	1 4	15 6	57 0	13 5
CR1/imv1	1377	448	928	173	26	147	42 7	3 5	39 1	57 0	12 6
	1120	399	721	87	17	70	82 1	2 1	80 0	57 0	8 6
	1509	406	1103	192	17	175	48 9	2 2	46 6	57 0	13 9
CR1/imuv	1363	263	1100	68	7	61	8 0	0 0	8 0	30 0	8 7
	1194	253	940	51	7	44	4 0	0 0	4 0	7 0	6 3
	4107	1234	2872	280	8	271	35 2	0 1	35 1	100 0	9 7
CR1/tm	4783	341	4442	354	15	338	89 7	1 3	88 5	149 0	7 2
	3887	323	3564	400	15	385	74 4	1 6	72 9	26 0	7 0
	4507	271	4236	242	7	235	35 1	0 0	35 1	31 0	7 4
CR2/imv1	617	423	194	77	21	56	10 9	9 1	1 8	0 0	11 5
	495	353	143	24	11	13	2 4	0 8	1 6	0 0	15 0
	1325	399	927	124	16	109	14 9	0 9	14 0	0 0	10 4
CR2/tm	4766	451	4315	389	15	373	55 2	0 8	54 4	83 0	9 5
	4823	438	4385	215	18	197	26 7	1 1	25 6	83 0	12 6
	3771	397	3373	279	14	265	76 4	0 7	75 7	83 0	10 0
RF/imuv	2081	332	1748	85	13	73	6 1	0 3	5 8	13 0	5 4
	3224	286	2938	146	7	139	16 4	0 2	16 2	48 0	5 0
	3876	262	3615	239	7	232	22 7	0 0	22 7	103 0	7 3
RF/imv1	779	426	354	27	13	13	2 0	0 9	1 1	55 0	5 1
	778	357	422	29	10	19	3 2	0 7	2 5	55 0	2 1
	881	362	519	37	12	26	4 8	0 9	3 8	55 0	2 9
RF/tm	2590	411	2179	65	11	54	52 4	0 4	52 0	55 0	7 0
	3074	385	2689	138	10	127	87 0	0 8	86 2	55 0	6 0
	2477	427	2050	53	11	42	5 4	0 2	5 2	55 0	1 3
Fw1/ imuv	1067	389	678	32	8	24	2 0	0 0	2 0	29 8	5 4
	1314	266	1048	66	9	57	10 4	0 3	10 1	29 8	5 7
	1967	267	1700	98	9	89	13 1	0 0	13 1	29 8	6 2
Fw1/3R	4324	296	4028	137	10	127	12 6	0 5	12 1	47 0	8 3
	3998	309	3689	160	11	149	23 5	0 3	23 1	62 0	6 0
	4129	333	3796	120	13	107	13 0	0 8	12 2	43 0	7 8

stove/fuel	CO2(t)c	co2(I)c	CO2(N)	CO(t)c	CO(I)c	CO(N)	CH4(t)c	CH4(I)c	CH4(N)	TNMOC	aac
Fw1/imv2	1449	393	1056	80	13	67	19.5	1.6	17.9	41.0	7.5
	1114	364	750	76	8	68	2.1	0.1	2.0	10.0	5.2
	2366	518	1848	78	12	66	17.7	0.6	17.1	3.0	6.6
Fw1imv1	1324	390	934	171	16	155	29.7	1.8	27.9	59.0	9.1
	1561	364	1197	192	19	173	30.0	2.1	27.9	54.0	5.8
	1327	377	950	169	21	149	42.1	2.3	39.8	84.0	9.5
Fw2/imv	1062	371	691	39	7	32	6.9	0.2	6.7	11.7	8.5
	821	343	479	25	7	19	3.2	0.2	3.0	11.7	8.4
	995	324	671	36	9	27	5.8	0.5	5.3	11.7	4.7
Fw2/im	3475	432	3043	132	11	121	32.3	0.9	31.4	38.9	3.4
	2979	453	2526	101	13	89	16.1	1.1	14.9	38.9	6.5
	2762	347	2414	78	8	70	15.6	1.1	14.4	38.9	5.7
Fw2/3R	1268	341	927	45	12	33	16.8	0.6	16.1	19.4	4.5
	1282	355	927	50	15	36	28.1	1.5	26.6	19.4	7.6
	1536	348	1188	55	14	41	27.4	2.3	25.0	19.4	5.2
Fw2/imv2	998	352	646	24	9	15	5.0	0.2	4.8	23.3	9.4
	1238	435	803	42	10	31	5.0	0.4	4.6	23.3	9.2
	1140	376	764	28	10	18	4.4	1.7	2.7	23.3	9.9
Fw2/imv1	1050	407	643	118	20	98	21.6	2.9	18.7	23.3	10.1
	1206	396	809	132	17	115	35.3	5.0	30.3	23.3	8.8
	1203	418	785	121	18	103	30.0	2.9	27.1	23.3	7.5

Note

CO2(t)C = Corrected concentration of CO2 in the flue gas

CO2(I)C = Corrected concentration of CO2 in the indoor

CO2(N)C = Net concentration of CO2

CO(t)C = Corrected concentration of CO in the flue gas

CO(I)C = Corrected concentration of CO in the indoor

CO(N)C = Net concentration of CO

CH4(t)C = Corrected concentration of CH4 in the flue gas

CH4(I)C = Corrected concentration of CH4 in the indoor

CH4(N)C = Net concentration of CH4

Table 16 Emission ratios and GHGs emission factors for various stove/fuel tested

stove/fuel	CO/CO2	CH4/CO2	TNMOC/CO2	AAC/CO2	K	FC	fuel dry(kg)	Emission factor (g/kg) CO2	CO	CH4	tnmoc	N2O
biogas/biogas	0.002	0.0003	0.0004	0.0004	0.003	37	0.092	1463	2	0.2	0.3	0.00
	0.003	0.0052	0.0021	0.0015	0.012	38	0.094	1451	3	2.8	1.2	
	0.001	0.0002	0.0004	0.0000	0.002	36	0.090	1465	1	0.1	0.2	
Dc/hara	0.132	0.1226	0.0551	0.0018	0.311	378	1.200	882	74	39.2	19.9	
	0.072	0.0128	0.0466	0.0019	0.133	381	1.200	1029	47	4.8	19.6	
	0.099	0.0226	0.0736	0.0025	0.197	381	1.200	972	61	8.0	29.3	
DC/imv2	0.037	0.0074	0.0653	0.0062	0.116	263	0.820	1057	25	2.8	28.2	
	0.038	0.0065	0.0646	0.0059	0.115	225	0.710	1043	25	2.4	27.5	
	0.070	0.0148	0.0935	0.0096	0.187	245	0.760	995	44	5.3	38.0	
DC/imv1	0.036	0.0069	0.0589	0.0051	0.107	300	0.928	1070	25	2.7	25.8	
	0.038	0.0046	0.0645	0.0050	0.112	296	0.920	1063	26	1.8	28.0	
	0.061	0.0140	0.0804	0.0070	0.162	310	0.960	1020	39	5.2	33.5	
DC/tm	0.071	0.0128	0.0483	0.0070	0.139	273	0.860	1022	46	4.7	20.2	
	0.084	0.0187	0.0450	0.0041	0.151	277	0.880	1003	53	6.8	18.5	
	0.074	0.0145	0.0410	0.0063	0.136	266	0.850	1013	47	5.3	17.0	
CB/angethi	0.135	0.0075	0.0301	0.0052	0.177	186	0.371	1559	133	4.2	19.2	
	0.121	0.0146	0.0174	0.0011	0.154	167	0.333	1590	122	8.4	11.3	
	0.103	0.0056	0.0268	0.0037	0.139	155	0.309	1611	105	3.3	17.7	
CC/angethi	0.197	0.0128	0.0094	0.0032	0.222	222	0.280	2380	298	11.0	9.1	
	0.201	0.0068	0.0131	0.0047	0.226	175	0.222	2361	301	5.8	12.7	
	0.143	0.0076	0.0095	0.0015	0.162	191	0.242	2493	227	6.9	9.7	
kero pressure	0.035	0.0012	0.0125	0.0006	0.049	42	0.050	2938	65	1.3	15.0	0.01
	0.027	0.0007	0.0174	0.0010	0.046	44	0.052	2948	50	0.8	20.9	0.02
	0.038	0.0011	0.0180	0.0010	0.058	40	0.048	2914	70	1.1	21.4	0.02
kero wick	0.007	0.0001	0.0122	0.0009	0.020	34	0.040	3023	13	0.1	15.0	0.01
	0.011	0.0004	0.0131	0.0003	0.025	39	0.046	3009	21	0.5	16.1	0.02
	0.010	0.0003	0.0108	0.0005	0.022	37	0.044	3018	19	0.3	13.3	0.01
lpg	0.006	0.0000	0.0186	0.0006	0.025	10	0.012	3078	12	0.0		0.05
	0.009	0.0001	0.0456	0.0005	0.056	9	0.011	3077	18	0.1		0.05
	0.007	0.0000	0.0105	0.0007	0.018	10	0.012	3099	14	0.0	13.3	0.03

stove/fuel	CO/CO2	CH4/CO2	TNMOC/CO2	AAC/CO2	K	FC	fuel dry (kg)	Emission factor (g/kg)				
								CO2	CO	CH4	tnmoc	N2O
CR1/imv2	0.050	0.0065	0.0333	0.0083	0.099	220	0.620	1183	38	2.8	16.1	0.08
	0.089	0.0140	0.0883	0.0204	0.212	251	0.690	1104	62	5.6	39.9	0.21
	0.093	0.0148	0.0543	0.0129	0.175	221	0.618	1118	66	6.0	24.8	0.13
CR1/imv1	0.158	0.0421	0.0614	0.0136	0.275	267	0.705	1091	110	16.7	27.4	0.14
	0.097	0.1109	0.0790	0.0119	0.299	263	0.720	1031	64	41.5	33.3	0.17
	0.158	0.0423	0.0517	0.0126	0.265	280	0.750	1084	109	16.6	22.9	0.12
CR1/imux	0.056	0.0073	0.0273	0.0079	0.098	179	0.440	1358	48	3.6	15.1	0.15
	0.047	0.0042	0.0074	0.0067	0.065	171	0.425	1389	41	2.1	4.2	0.18
	0.095	0.0122	0.0348	0.0034	0.145	191	0.470	1302	78	5.8	18.5	0.05
CR1/tm	0.076	0.0199	0.0335	0.0016	0.131	238	0.600	1285	62	9.3	17.6	0.03
	0.108	0.0204	0.0073	0.0020	0.138	266	0.680	1264	87	9.4	3.8	0.04
	0.056	0.0083	0.0073	0.0017	0.073	249	0.630	1352	48	4.1	4.0	0.04
Cr2/imv1	0.288	0.0092	0.0000	0.0590	0.356	337	1.000	911	167	3.0	0.0	
	0.092	0.0111	0.0000	0.1049	0.208	320	0.960	1014	59	4.1	0.0	
	0.117	0.0151	0.0000	0.0113	0.144	322	0.980	1055	78	5.8	0.0	
CR2/tm	0.087	0.0126	0.0192	0.0022	0.121	294	0.880	1093	60	5.0	8.6	
	0.045	0.0058	0.0189	0.0029	0.072	340	1.040	1120	32	2.4	8.7	
	0.079	0.0224	0.0246	0.0030	0.129	316	0.960	1069	53	8.7	10.8	
RF/imux	0.042	0.0033	0.0074	0.0031	0.055	165	0.393	1463	39	1.8	4.5	
	0.047	0.0055	0.0163	0.0017	0.071	172	0.390	1510	46	3.0	10.1	
	0.064	0.0063	0.0285	0.0020	0.101	187	0.420	1486	61	3.4	17.3	
RF/imv1	0.037	0.003	0.0000	0.0143	0.055	236	0.610	1171	28	1.3	74.4	
	0.044	0.006	0.0000	0.0049	0.055	203	0.502	1253	35	2.7	66.8	
	0.049	0.007	0.0000	0.0056	0.062	240	0.580	1298	41	3.5	56.3	
RF/tm	0.025	0.024	0.0252	0.0032	0.077	267	0.560	1623	25	14.0	16.8	
	0.047	0.032	0.0205	0.0022	0.102	286	0.635	1500	45	17.4	12.5	
	0.020	0.003	0.0268	0.0006	0.050	221	0.510	1515	20	1.4	16.6	
Fw1/imuv	0.036	0.003	0.0439	0.0079	0.090	147	0.395	1256	28	1.3	22.5	0.19
	0.054	0.010	0.0284	0.0055	0.098	166	0.423	1315	45	4.6	15.3	0.13

								Emission factor (g/kg)				
stove/fuel	CO/CO2	CH4/CO2	TNMOC/CO2	AAC/CO2	K	FC	fuel dry(kg)	CO2	CO	CH4	tnmoc	N2O
Fw1/3R	0 053	0 008	0 0175	0 0036	0 081	143	0 402	1203	40	3 4	8 6	0 07
	0 032	0 003	0 0117	0 0021	0 048	175	0 505	1215	24	1 3	5 8	0 03
	0 040	0 006	0 0168	0 0016	0 065	158	0 458	1189	31	2 7	8 2	0 03
Fw1/imv2	0 028	0 003	0 0113	0 0020	0 045	171	0 468	1281	23	1 5	5 9	0 03
	0 064	0 017	0 0388	0 0071	0 127	157	0 490	1040	42	6 4	16 5	0 10
	0 091	0 003	0 0133	0 0069	0 114	157	0 490	1053	61	1 0	5 7	0 14
Fw1/imv1	0 036	0 009	0 0016	0 0036	0 050	156	0 480	1136	26	3 8	0 8	0 06
	0 166	0 030	0 0632	0 0098	0 269	186	0 680	791	83	8 6	20 4	0 08
	0 144	0 023	0 0451	0 0049	0 218	220	0 720	921	84	7 8	17 0	0 08
Fw2/ imuv	0 156	0 042	0 0884	0 0100	0 296	196	0 640	867	86	13 2	31 3	0 09
	0 046	0 010	0 0169	0 0122	0 085	127	0 365	1174	35	4 1	8 1	0 07
	0 039	0 006	0 0245	0 0175	0 088	86	0 300	969	24	2 2	9 7	0 08
Fw2/ tm	0 041	0 008	0 0174	0 0070	0 073	106	0 335	1080	28	3 1	7 7	0 07
	0 040	0 010	0 0128	0 0011	0 064	144	0 520	953	24	3 6	5 0	0 01
	0 035	0 006	0 0154	0 0026	0 059	142	0 495	991	22	2 1	6 2	0 02
Fw2/3R	0 029	0 006	0 0161	0 0023	0 053	148	0 480	1078	20	2 3	7 1	0 02
	0 036	0 017	0 0209	0 0048	0 079	143	0 450	1083	25	6 8	9 3	0 05
	0 039	0 029	0 0209	0 0082	0 096	154	0 490	1054	26	10 9	9 0	0 05
Fw2/imv2	0 034	0 021	0 0163	0 0044	0 076	143	0 530	920	20	7 0	6 1	0 03
	0 023	0 007	0 0361	0 0145	0 081	131	0 593	751	11	2 0	11 1	0 05
	0 039	0 006	0 0290	0 0115	0 085	125	0 545	776	19	1 6	9 2	0 04
Fw2/imv1	0 024	0 004	0 0305	0 0129	0 071	138	0 565	835	13	1 1	10 4	0 04
	0 152	0 029	0 0362	0 0158	0 233	184	0 675	811	78	8 5	12 0	0 05
	0 142	0 037	0 0288	0 0108	0 219	174	0 690	757	68	10 3	8 9	0 04
	0 131	0 035	0 0297	0 0096	0 205	161	0 700	702	58	8 8	8 5	0 04

Explanatory remarks 1 All emissions factors were calculated from the corrected values

2 K is the sum of emission ratios to CO2 (CO/CO2 + CH4/CO2 + Tnmoc/CO2 + AAC/CO2)

3 FC = [(fuel consumed * Fuel carbon) + (lighter consumed * lighter carbon)] - [(char produced * char carbon) + (Ash produced*Ash carbon)]

According to the Indian standard for domestic LPG stoves the limit for CO/CO$_2$ emission ratio is 0.02 (BIS, 1984) In our experiments the mean CO/CO$_2$ ratio for biogas LPG and kerosene wickstove are below this limit. The ratio for all biofuels and charcoal are much higher than this value The highest CO/CO$_2$ ratio is found for charcoal In the Manila Pilot study also the CO/CO$_2$ ratio for an LPG and kerosene stove were below the limit specified by Indian Standards domestic LPG and highest value was for charcoal (Smith *et al*, 1992)

CO emission ratio for the wood fuel varies from 0.03-0.06 The higher emission ratio 0.15 was recorded for wood in improved mud stove The CO emission ratios for the two wood species in traditional mud and three rock stove are between 0.03-0.04 Hao *et al* (1990) reported the CO emission ratio for wood stove as 0.06 for open combustion range of biomass type Our values for wood in traditional and three rock stove (open combustion) is lower than this value The range of a CO emission ratio for the improved vented1 (0.14-0.16) is much higher than the CO emission ratio for some of improved mud stove (between 0.04-0.07) reported in FAO 1993 Whereas the range of CO emission ratio for wood fuel in improved vented2 is within this range (0.03-0.6) The CO emission ratio for wood in improved unvented stove (0.04) is same as the value for Priagni (improved unvented) given in FAO, 1993 The CO emission ratio for dung and crop residues are higher than the ratio for wood fuel in all types of stoves tested This is similar to the findings of the earlier study by FAO Except dungcake in all other tested fuels, the CO ratio is higher in improved vented1 (mud) stove

The N$_2$O values are not available for all fuel/stove combinations tested. For the available N$_2$O values the N$_2$O/CO$_2$ ratios were calculated and found less than 0.007 quoted by Crutzen and Andreaw (1990)

Among the various fuel/stove tested the CO$_2$ emission factor is high for LPG This may be due to the high carbon content in the fuel (about 86%) and proper combustion efficiency of the stove which inturn lead to high CO$_2$ and less of a product of incomplete combustion (CO, CH$_4$, TNMOC) The CO emission factor is high for charcoal (276 g/kg) and low for biogas (2g/kg) Among the various biofuels tested the CO emission factor for Fuel wood1 (*eucalyptus*) in various stove varies from 15-85 For wood in traditional and three rock stove the emission factors are less than 30 In root fuel and paddy straw also the emission factors for improved stoves are higher than the traditional stoves Ahuja *et al* 1987 also reported that the emission factors for improved stoves are higher than the traditional stove There is some evidence that design changes directed at improving efficiency actually increase emission factors for most pollutants (TERI 1985)

CO emission factors for crop residues are higher than that of wood. CO emission factor for dung cake lies between wood and crop residues CH_4 emission factors are low for LPG, kerosene wick stove and high for crop residues in improved stove Among the three improved stove (improved UV, improved V_1, and improved V_2), in most of the cases the emission factor is high for improved V_1 stove and low for improved V_2 stove Comparatively the efficiency is high in improved V_2 stove. The high efficiency and low emission factor in case of improved V_2 may be due to the ceramic lining and the firebox design that helps in proper air flow and in turn enhance the complete combustion

Figures 21, 22, 23 & 24 show the emission factors of CO_2, CO, CH_4 & TNMOC for various fuel/stove tested.

The average emission factors for various fuel/stove combination were compared with the earlier reported values (Table 17)

Table17 Comparison of emission factors with other studies

stove fuel	CO2	CO	CH4	TNMOC	N2O	manila pilot study results §					teri co(¶)	other
						CO2	CO	CH4	TNMOC	N2O		
biogas burners	1460	2	1.0	0.6								
DC hara	961	61	17.3	22.9								
DC imv 2	1032	31	3.5	31.3								
DC imv 1	1051	30	3.2	29.1								
DC tm	1013	49	5.6	18.5							26-67	
CB angethi	1587	120	5.3	16.1								
CC angethi	2411	276	7.9	10.5		2740	230	8	4	0.04		
kero pressure	2933	62	1.1	19.1	0.02							
kero wick	3016	18	0.3	14.8	0.01	3030	38	1	11	0.05	33-93	
lpg	3085	15	0.05	13.3	0.04	3110	24	0.04	3	0.03		
CR1/imv 2	1135	55	4.8	26.9	0.14							
CR1/imv1	1069	94	24.9	27.9	0.14							
CR1/imuv	1350	56	3.9	12.6	0.13						76-114	
CR1/tm	1300	65	7.6	8.5	0.04							
CR2/imv 1	993	102	4.3									
CR2/tm	1094	48	5.4	9.3								
RF/imuv	1486	48	2.7	10.6								
RF/imv 1	1241	34	2.5									
RF/tm	1546	30	10.9	15.3								
Fw1 imuv	1258	38	3.1	15.5	0.13							
Fw1 3R	1228	26	1.8	6.6	0.03							
Fw1 imv 2	1076	43	3.7	7.7	0.10							
Fw1 imv 1	860	85	9.8	22.9	0.08							
Fw2 imuv	1074	29	3.1	8.5	0.07						24-39	

						manila pilot study results §						
stove/fuel	CO_2	CO	CH_4	TNMOC	N_2O	CO_2	CO	CH_4	TNMOC	N_2O	teri co(¶)	other
Fw2/ tm	1007	22	2 7	6 1	0 02	1560	99	8	12	0 06	13-68	17-130(‡)
Fw2/3R	1019	24	8 3	8 1	0 04							
Fw2/imv2	788	14	1 6	10 2	0 04							
Fw2/imv1	757	68	9 2	9 8	0 04							

sorce

§ Smith et al 1992

¶ TER,1987

‡ Smith KR,1987

The table 17 shows for LPG the CO_2, CO and CH_4 emission factors are comparable to the emission factors for LPG found in Manila Pilot study. But the TNMOC emission factor (13.3 g/kg) is much higher than the 3g/kg reported in the Manila study For kerosene wick the CO_2, TNMOC emission factors are close to the Manila study results But CO and CH_4 emission factors are less than the Manila study results. The CO. emission factor for kerosene wick stove is even less than that of 41 reported by TERI (1987) For charcoal the CO_2, CO, & CH_4 emission factors of the present study are well comparable to the Manila study result But the TNMOC emission factor of the present study is higher than that of the Manila reported value

For fuel wood the CO emission factors is lower than the CO emission factor 100g/kg reported in the Manila study. But it falls in the range of 13-68 reported by TERI (1987) and the range 17-130 reported by Smith K R (1987). CO emission factor for dung cake and crop residues are within the range reported by TERI (1987).

5.3. Inventory of GHG emissions from cookstoves in India

Inventory of GHG emissions from cookstoves need an accurate fuel use estimation in the country Due to some limitations it is difficult to have an accurate fuel use estimation for India The limitations are listed below

- In India a wide variety of fuels such as liquid petroleum gas (LPG), kerosene, biogas, coal, coke, charcoal, fuelwood, dungcakes, root fuel and crop residues (mustard stalks jute stalks, cotton stalks, rice straw, etc.) are used for cooking purposes
- A variety of stoves such as metal stove, mud stove (with single pot, two pots) and ceramic stoves are used with a immense efforts of Ministry of Non-conventional Energy Sources (MNES) In the improved stoves also number of varieties are available
- The life of the improved stoves are also limited (not more than 2 years) So the number of improved stoves in working condition is very less
- In India due to the large variation in the agro climatic conditions & life style, the types of crop produced also vary from region to region Depending on the type of crops produced, the crop residues used as fuel also vary
- There is a considerable variation in the types of food cooked, cooking practices etc For example the stove known as Hara, employed for simmering milk and fodder preparation consume large quantity of dung cake as a fuel is common in northern states of India This stove is not in use in southern region

- Energy consumption levels also vary for different agro climatic regions (397-1393 useful kcal/day/person) The biofuel consumption database for India which was made based on the rural energy surveys is found to be quite inadequate. There is a wide variation in the existing rural energy database of India (Joshi V, Sinha CS, 1993)

With these above mentioned limitations we attempted to estimate the amount of fuel used in India for the year 1990/91, which can be further used for the GHG emission inventory from cookstoves for India

Datas, Assumptions and steps involved in fuel use estimation

Biofuel estimation Large amount of biofuels are used in rural areas Three different sources of biofuel consumption estimates for rural India are available They are

Rural Energy Database (REDB) REDB is based on the analysis of data compiled for 638 villages in 17 states spread over 14 agro climatic regions and covering 39000 households

Integrated Rural Energy Planning Programme (IREP) IREP database is compiled by the Planning Commission of Government of India based on block level surveys covering nearly 250 blocks

National Council for Applied Economic Research (NCAER) database The NCAER data is based on surveys conducted in 7500 households (in rural areas) selected from 600 villages in 300 districts

Among these three estimates, the REDB estimates are on the higher side and NCAER estimates are on the lower side So we have used IREP estimates in our fuel use estimation of rural India even though IREP database have the following uncertainities

1. The IREP estimate of crop residues for West Bengal is zero, whereas it is known that crop residues are used extensively in the state
2. There are no estimates for Goa.
3. There are no data for dungcake and crop residues for the north-eastern states.

Step involved in stove wise biofuel consumption estimation for rural India

- The state wise biofuel estimation fugure given by IREP estimates are divided by total number of households in different states of rural India to get the per household consumption

- The State wise data distribution of improved chulhas till March'91 was collected from MNES
- From the total number of improved cookstoves installed, the number of improved cookstoves in working condition was calculated based on the assumption that only 60% are functional.
- In the improved stoves 10% of the improved cookstoves are assumed to be improved metal and 90% of the improved cookstoves are mud stoves
- The remaining households are assumed to be using traditional stoves
- It is estimated that there is only one stove in use in each household
- It is assumed that each stove consumes the three biofuels in the same proportion given by IREP
- For Biofuel consumption in traditional stoves the number of stoves are multiplied by the household consumption of biofuels
- The total biofuel in improved cookstoves biofuel consumption is estimated by multiplying the household consumption by 0 80 assuming that the improved cookstoves save 20% fuel consumption and further multiplied by the total number of improved stoves working.

These above mentioned steps are also shown as a flow chart in figure 25

The number of rural households, improved stoves and biofuel consumption in each stove in rural India for the year 90/91 is given in the Table 18

Table 18. State-wise list of rural households, penetration of improved stoves, and biofuel consumption

State/Union Territories	No of rural hosueholds	No of improved stoves installed till 31 3 91	No of imp stoves working			No of traditional stoves	Consumption of biofuels					
							Total (million tonnes/year)			Per household (tonnes/year)		
			Metal stoves	Mud stoves	Total		Fuel-wood	Dung-cake	Crop residue	Fuel-wood	Dung-cake	Crop residue
Andhra Pradesh	9579605	762598	45756	411803	457559	8817007	10 8	2 9	3 6	1 13	0 30	0 38
Arunachal Pradesh	129956	6042	363	3263	3625	123914	0 5	0 0	0 0	3 85	0 00	0 00
Assam	3265110	101357	6081	54733	60814	3163753	12 3	0 0	0 0	3 77	0 00	0 00
Bihar	10682935	509946	30597	275371	305968	10172989	26 9	9 9	13 0	2 52	0 93	1 22
Goa	120758	48429	2906	26152	29057	72329	0 0	0 0	0 0	0 00	0 00	0 00
Gujarat	4289530	534200	32052	288468	320520	3755330	9 1	2 2	3 0	2 12	0 51	1 70
Haryana	1825870	569136	34148	307333	341482	1256735	1 7	2 9	4 3	0 93	1 59	2 36
Himalchal Pradesh	830856	360886	21653	194878	216532	469971	3 3	0 4	0 2	3 97	0 48	0 24
Karnataka	4920170	470886	28313	254818	283132	4448285	8 3	1 8	3 2	1 69	0 37	0 65
Kerala	3908425	220333	13220	118908	132200	3688092	10 0	0 0	1 6	2 56	0 00	0 41
Madhya Pradesh	8243710	845023	50701	456312	507014	7398687	13 1	1 8	1 5	1 59	0 22	0 18
Maharashtra	8410655	662639	39758	357825	397583	7748016	16 0	6 7	5 8	1 90	0 80	0 69
Manipur	203193	21576	1295	11651	12946	181617	0 8	0 0	0 0	3 94	0 00	0 00
Meghalaya	256914	10200	612	5508	6120	246714	0 9	0 0	0 0	3 50	0 00	0 00
Mizoram	60348	7694	462	4155	4616	52654	0 2	0 0	0 0	3 31	0 00	0 00

State/Union Territories	No of rural households	No of improved stoves installed till 31 3 91	No of imp stoves working			No of traditional stoves	Consumption of biofuels					
							Total (million tonnes/year)			Per household (tonnes/year)		
			Metal stoves	Mud stoves	Total		Fuel-wood	Dung-cake	Crop residue	Fuel-wood	Dung-cake	Crop residue
Nagaland	168918	7000	420	3780	4200	161918	0 6	0 0	0 0	355	0 00	0 00
Orissa	4773275	339528	20372	183345	203717	4133747	11 2	0 6	0 4	2 50	0 13	0 09
Punjab	2257090	515796	30948	278530	309478	1741295	1 9	3 4	5 0	0 84	1 51	2 22
Rajasthan	5441095	1080764	64846	583613	648458	4360331	4 3	2 1	0 8	0 79	0 39	0 15
Sikkim	67318	18597	1116	10042	11158	48721	0 2	0 0	0 0	2 97	0 00	0 00
Tamil Nadu	8027750	742420	44545	400907	445452	7285330	8 5	2 0	2 5	1 06	0 25	0 31
Tripura	430649	5971	358	3224	3583	424678	1 4	0 0	0 0	3 26	10 00	0 00
Uttar Pradesh	16784590	1209179	72551	652957	725507	15575411	21 9	17 2	17 3	1 30	1 02	1 03
West Bengal	8384490	317179	19031	171277	190307	8067311	4 4	0 0	0 0	0 52	0 00	0 00
Union Territories	285878	151096	9066	81592	90658	134782	0 4	0 3	0 4	1 40	1 05	1 40
TOTAL	103049088	9519475	571169	5140517	5711685	93529617	168 7	54 2	62 6	54 96	9 55	12 03

For biofuel consumption in urban areas as per the 1991 census only 30% of the urban population use biofuels. So it is assumed that 30% of the urban population use fuelwood in Traditional stove with a consumption norm of 1 kg/day/person The total urban consumption of fuelwood is calculated to be 23 8 million tonnes/year

Charcoal consumption in cookstoves for the year 1990/91 is calculated from the charcoal production data. FAO (1992) reported that in India 1984000 tonnes of charcoal were produced in the year 1991 Most of the charcoal produced were used for small scale industries such as Bakeries. Laundaries, silk rereeling, jewellery making etc so it is assumed only 1/4th of the charcoal produced was used in cookstove (Angethi)

Biogas consumption is estimated from the number of family biogas plant installed. Till 1990/91 1403574 family type biogas plants were installed (TERI 1997) The plant capacity is 2m^3/day As per the NCAER survey only 66% of the biogas plants installed are in working condition (NCAER 1993) Based on the assumption that 66% of the installed biogas plants produce biogas with the 70% of the plant capacity it is estimated that 666 million m^3 of biogas was consumed in India.

Commercial Fuels (LPG, kerosene) In India largest fuel consumed in cookstoves are biofuels Commercial fuels such as LPG and kerosene are used by 30% of the population and they use mainly in urban areas For the year 1990-91 total LPG consumption was 2.4/5 million tonnes. Out of which 78 4% (1 894 million tonnes) was used for domestic purpose (Mo P N G, 1992).

The kerosene consumption was 8 4 million tonnes/year There is an uncertainty regarding the consumption of kerosene for cooking and lighting. In 1991, 60% of the kerosene was used in rural sector (MoF 1992). In the rural sectors kerosene is mainly used for lighting purposes (NCAER (1987) indicated for a cooking: lighting is a ratio of 0 186:1 in rural areas and 3.46:1 for urban areas Kishore VVN, Joshi V (1995) reported that the predominant use of kerosene for lighting in rural areas and for cooking in urban areas continue even now Based on this, it is estimated that 3.98 million tonnes of kerosene was used for cooking during 1991. In which 1.158 million tonnes of kerosene was used for cooking in rural and the rest 2.819 million tonnes were used in urban area for cooking. For cooking purpose, two types of kerosene stoves such as wick and kerosene pressure stove are in use In the absence of data on how much is used in wick and pressure stove it is assumed that in urban area 60% of the kerosene users use in wick stove and 40% use in pressure stove. In the rural area 60% of the kerosene users use pressure stove and the rest in wick stove.

The estimated stove-fuel wise consumption of various fuels in India for the year 1990/91 is given in the Table19

Table 19 Stove wiuse consumption of fuels in India (million tonnes/year)

Stove	Fuelwood	Dung cake	Crop residues	Charcoal	Kerosene	LPG	Biogas (million m^3)
Improved metal	0.71		0.3				
Improved mud	6.36	2.77	2.9				
Traditional	193.38	31.63	58.6				
Hara		19.12					
Angethi				0.5			
Pressure					1.82		
Wick					2.16		
LPG burner						2.1	
Bio burner							666
Total	190.45	53.52	61.8	0.5	3.98	2.1	666

These stove wise fuel use estimation are used for greenhouse gases inventory The The estmated emission factors for various stove/fuel combinations were averaged and used for GHGs inventory We tested 2 types of improved stoves (improved mud and improved mud with ceramic coating) Among these two improved stoves, improved mud stove with ceramic coating is not much in use Only limited number of stoves were disseminated. So we have taken the weighted average of the improved mud: improved mud with ceramic coating (90:10) to get one emission factor for improved mud stove.

Similarly for wood species in traditional stove we have taken the weighted average of wood in traditional mud and 3 rock in the ratio of (90·10). The 2 species of wood were averaged by giving equal weightage

In crop residues we tested 2 varieties (mustard stalk and paddy straw) In most of the region in India, only stalk variety is used as a fuel Straw is mainly used as cattle fodder So it is assumed that all crop residues are stalk variety and used the emission factor for mustard stalk

The weighed average emission factors and estimated greenhouses emissions from various stove fuel combinations used in India are given in the Table 20

Table 20. Weighed average emission factor and GHG emissions from various stove/fuel combinations in India (1990-91)

	Emission factor (g/kg)					GHG emission (tg/y)				
Stove/Fuel	CO_2	CO	CH_4	Tnmoc	N_2O	CO_2	CO	CH_4	Tnmoc	N_2O
Biogas	1460	2	1	0 6		0 972	0 001	0 001	0	0
LPG	3085	15	0 05	13 3	0 04	6 479	0 032	0 0001	0 028	0 00008
Kerosene										
Wick	3016	18	0 3	14 8	0 01	6 515	0 039	0 0006	0 032	0 00002
Pressure	2933	62	1	19	0 02	5 338	0 113	0 0018	0 035	0 00004
Fuel wood										
Traditional mud	1019	22	3	6 2	0 0215	186 8	4 089	0 538	1 142	0 00394
Improved mud	821	72	9	15 6	0 061	5 221	0 456	1 617	2 863	0 01119
Improved metal	1167	34	3	12	0 1	0 828	0 024	0 0022	0 009	0 00007
Crop res										
Traditional mud	1300	65	8	8 5	0 04	76 18	3 809	0 440	0 498	0 00234
Improved mud	1076	90	23	27 9	0 14	3 119	0 261	0 0667	0 081	0 00041
Improved metal	1350	56	4	12 6	0 13	0 405	0 017	0 0011	0 004	0 00004
Dung cake										
Traditional mud	1013	49	6	18 5		32 04	1 550	0 1771	0 585	0
Hara	961	61	17	22 9		18 37	1 166	0 3308	0 438	0
Improved mud	1049	30	3	29 2		2 908	0 083	0 0089	0 081	0
Charcoal										
Angethi	2411	275	8	10 4		1 206	0 138	0 0040	0 005	0

The table shows that the GHG emissions from Biofuels especially from wood are higher than the emissions from other fuels as expected The estimates of GHGs emissions for various stove/fuel are summed up and the summary is presented in the table 21.

Table 21 Invetory of GHG emissions from India (1990-91)

Fuel	CO_2 (tg/y)	CO (tg/y)	CH_4 (tg/y)	Tnmoc (tg/y)	N_2O (tg/y)
Biofuels	327 080	11 593	3 185	5 704	0 018
LPG	6 479	0 0315	0 0001	0 0279	0 00008
Kerosene	11 853	0 152	0 0025	0 067	0 0001
Biogas	0 972	0 001	0 001	0	0

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Figure 1 Cook stove carboncycle

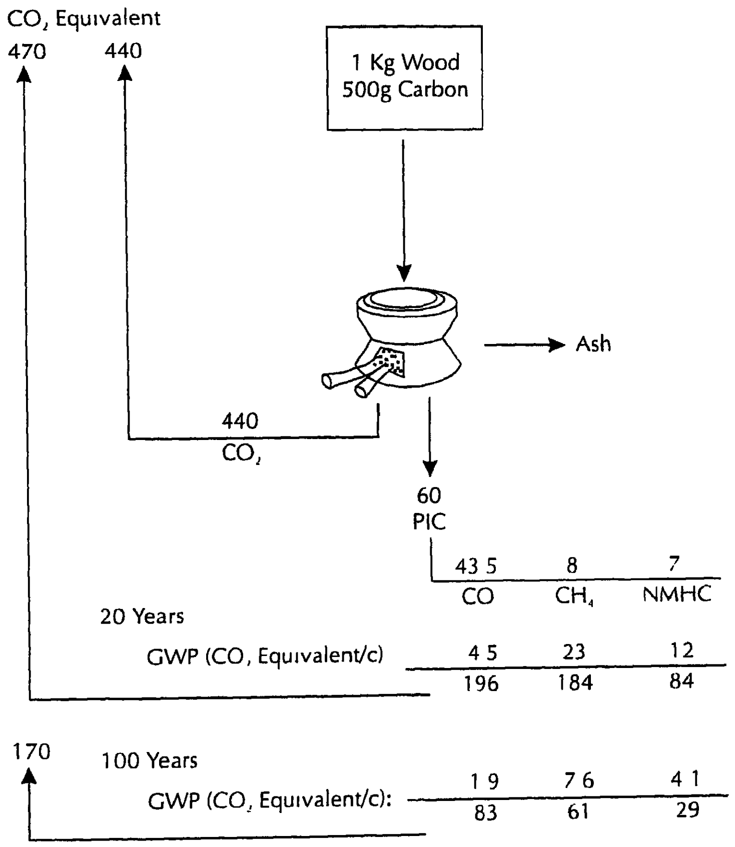
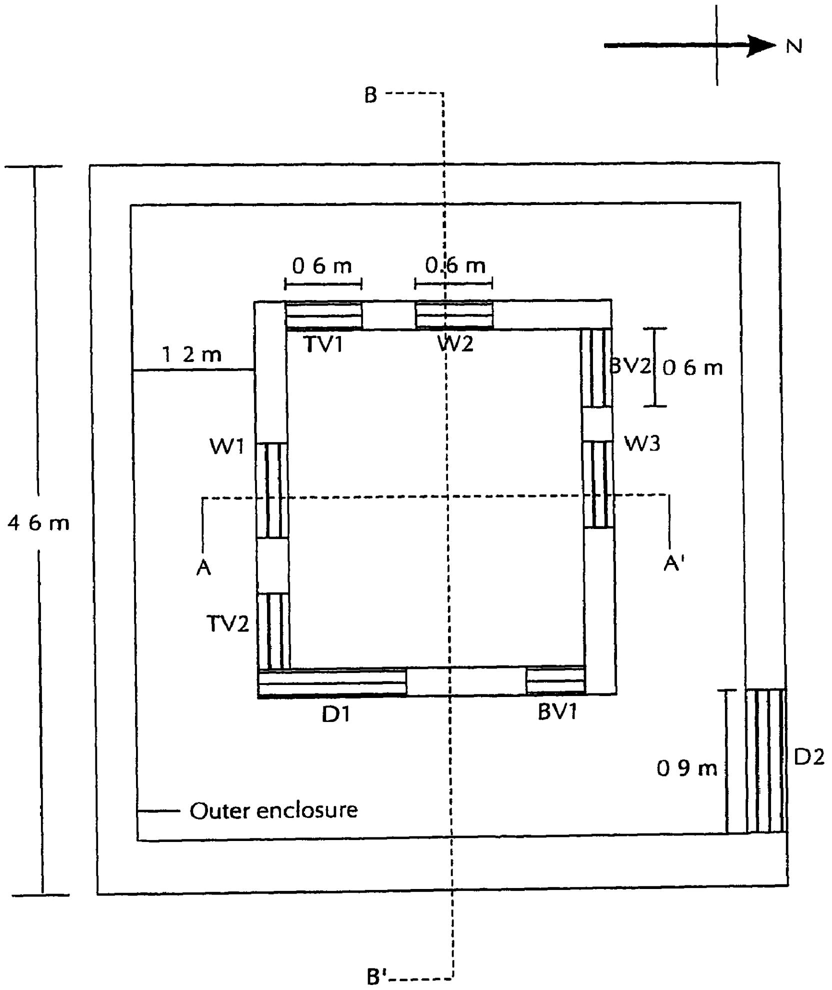


Figure 2 Simulated Rural Kitchen



D1 & D2=Door=2 m × 0 9 m
wall thickness=2.54 cm
BV1 & BV2=Bottom ventilators=0 6 × 0 3, 0 3 m
TV1 & TV2=Top ventilators=0 6 × 0 3, 0 2 m

Figure 3. Simulated Rural Kitchen (A-A')

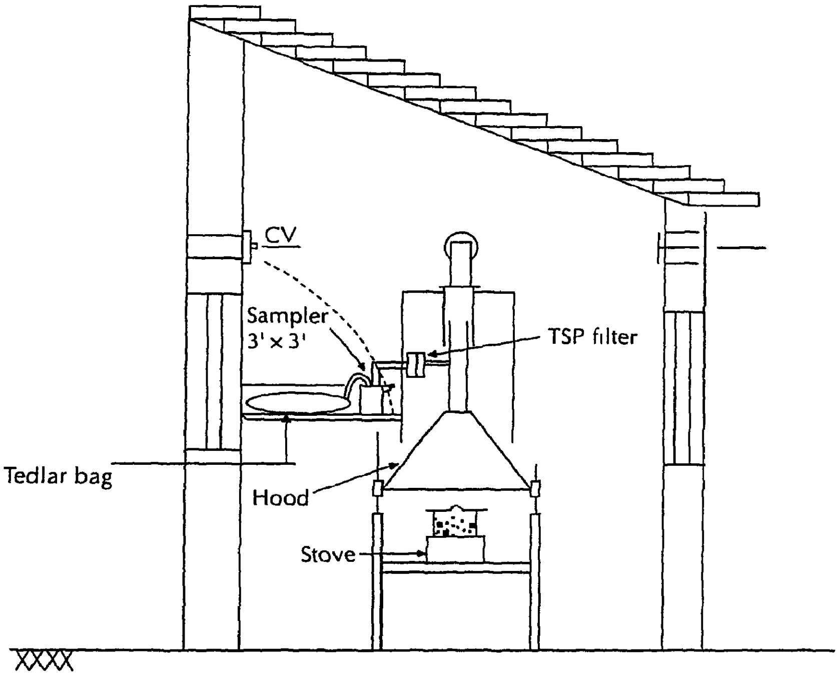


Figure 4 Simulated Rural Kitchen (B-B')

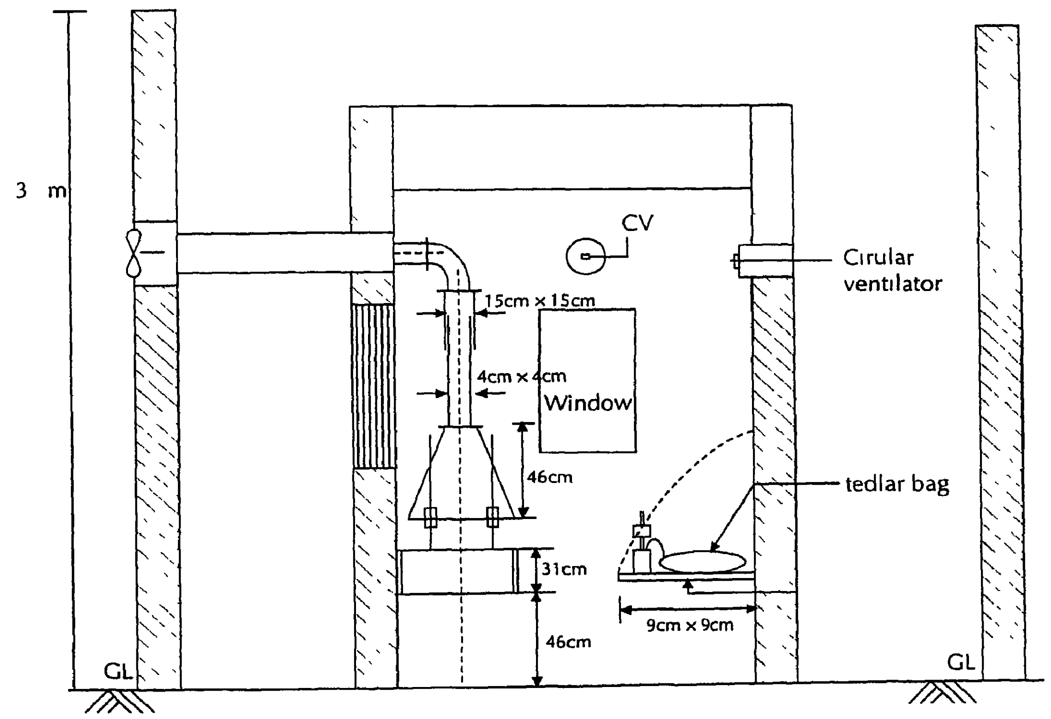


Figure 5 Hood arrangement for stove with flue

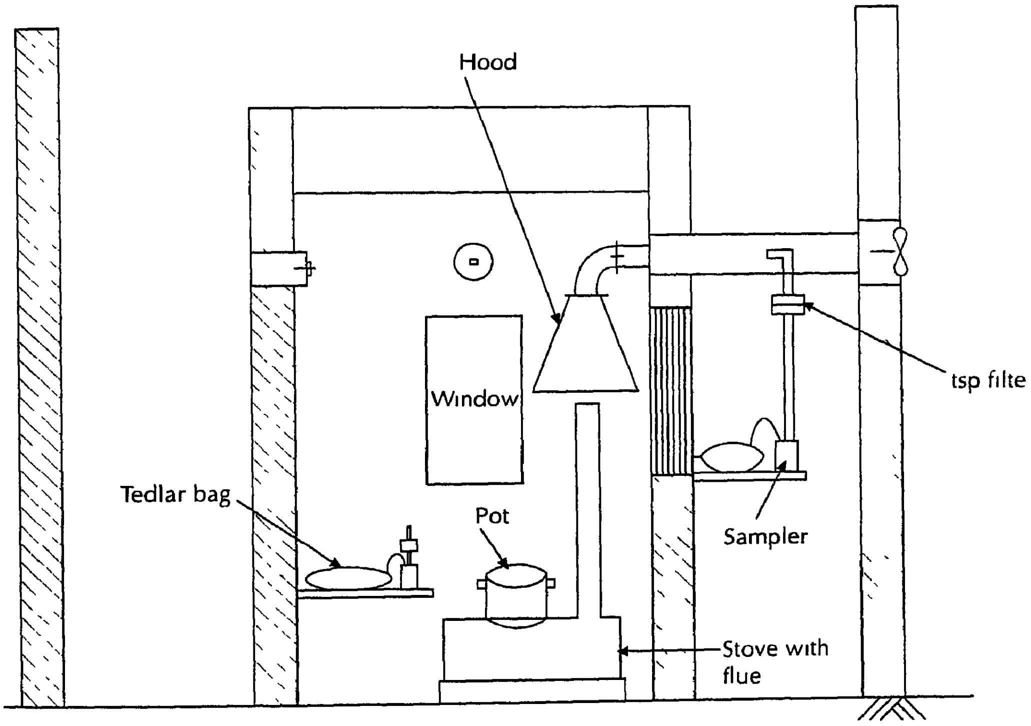
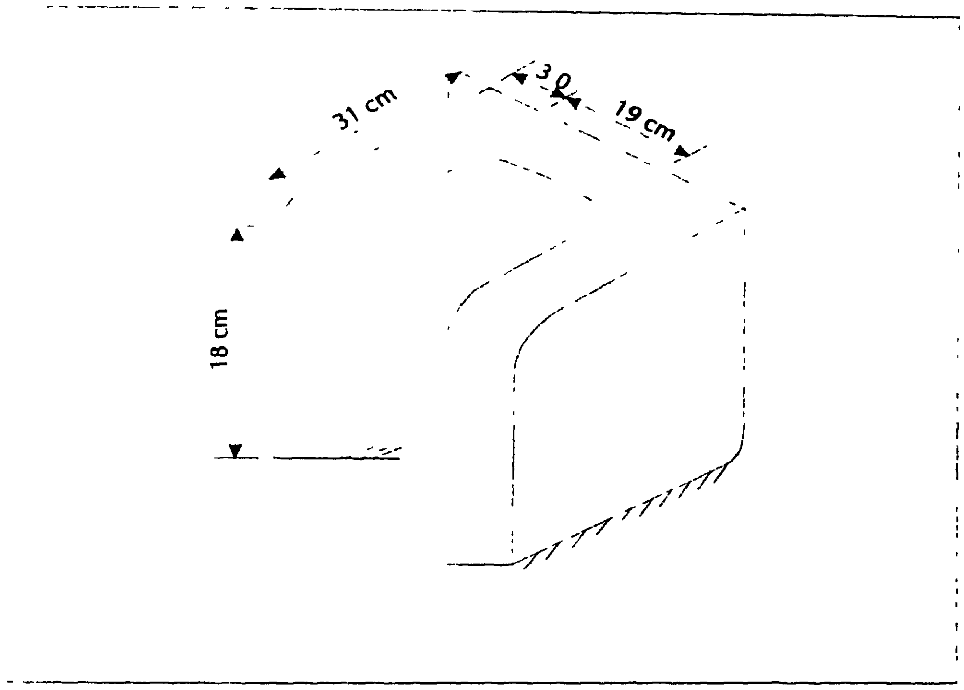
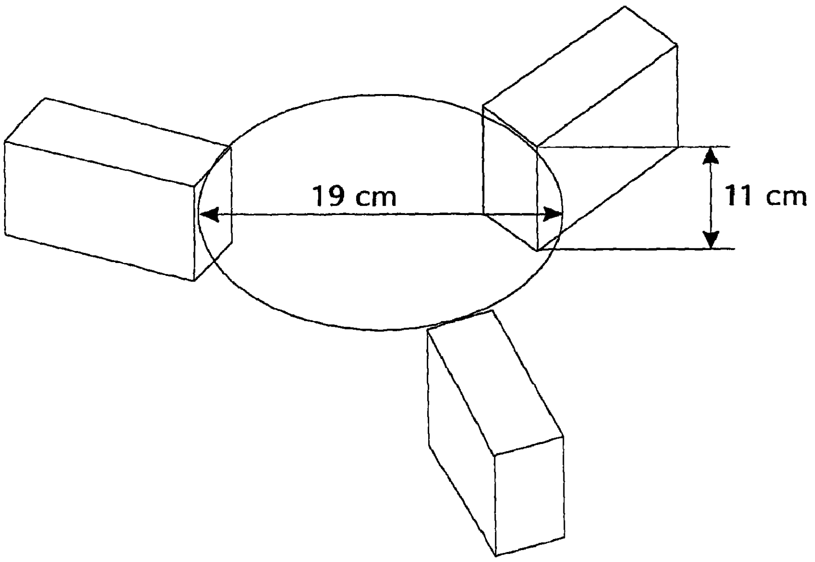


Figure 6. Traditional mud stove



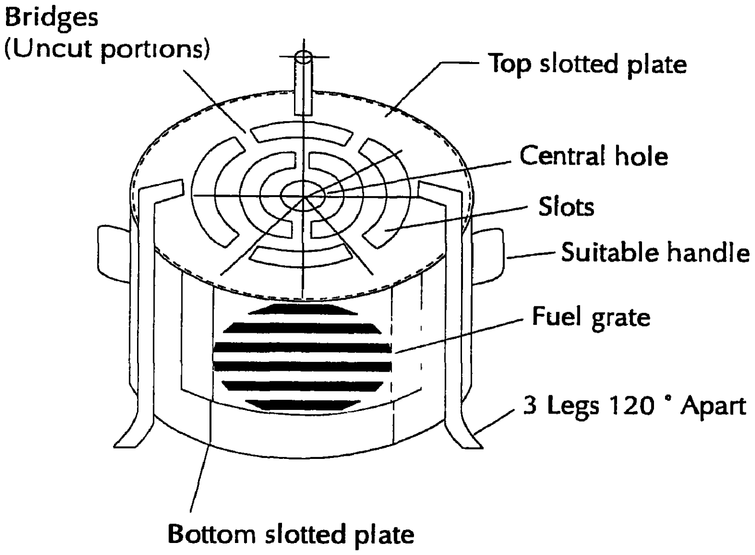
Places : Rural and urban poor households
User : Rural and Urban poor
Fuel type : Fuel wood, twigs, crop residues & dung cakes
material : Clay, mud
Stove maker : User
Production method : Make 'U" shape wall with clay and coat with mud.
Price : Nil

Figure 7 : Three Rock arrangement



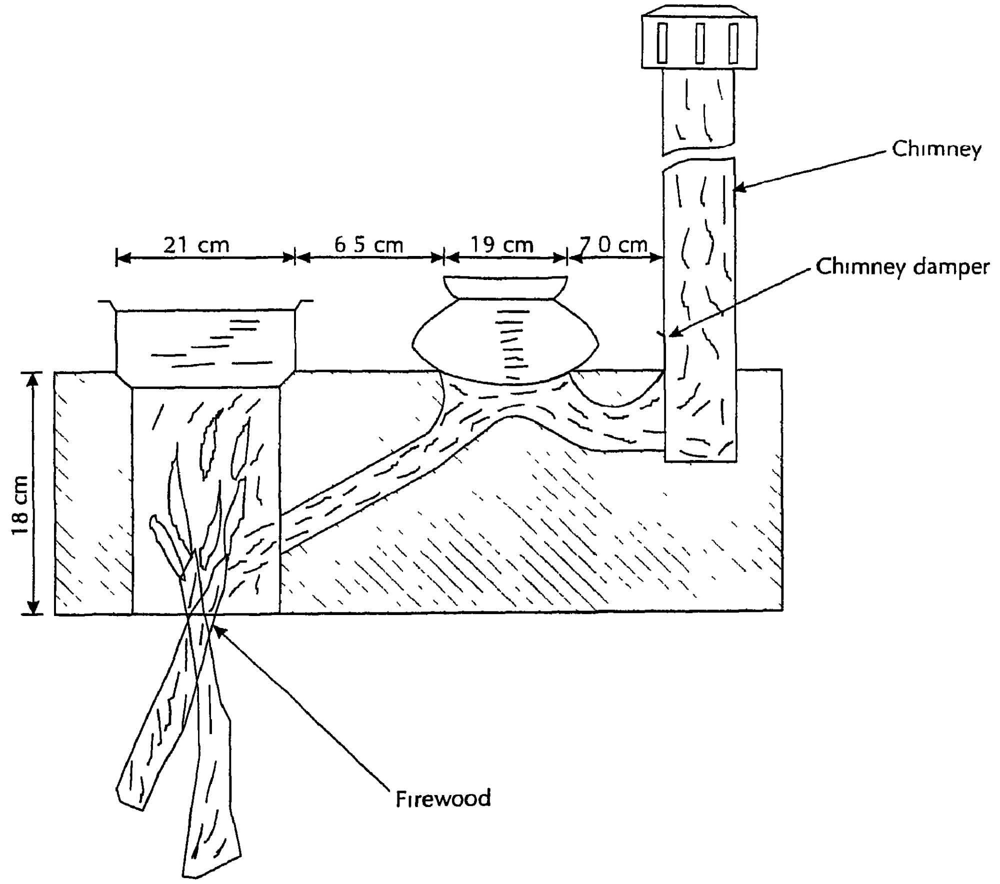
Country, places : Open place, court yard
User : Nomadic people, workers involved in construction, people who live in pave ments
Fuel type : Fuel wood, twigs, crop residues
material : 3 stones
Stove maker : User
Production method : arrangimg 3 stones in star configuration
Price : Nil

Figure 8. Improved Unvented [illegible]



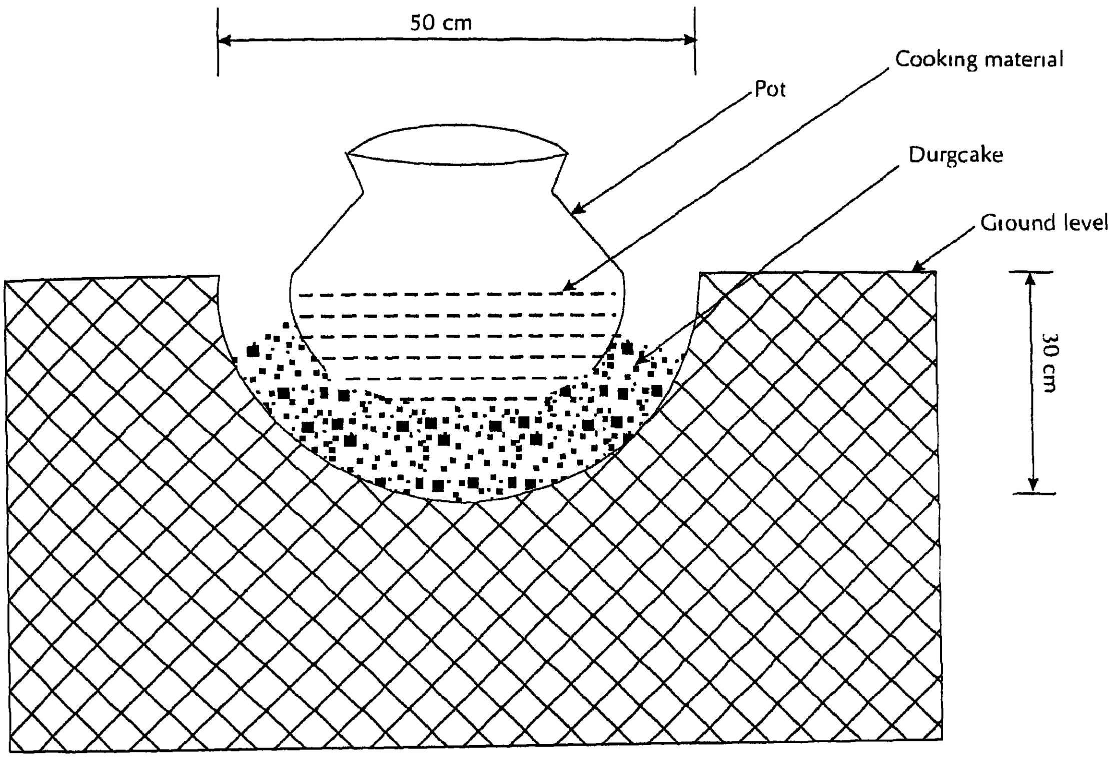
Country, places : All parts of India
User : About 3 million families in all parts of the country
Fuel type : wood and twigs
material : metal sheets and metal rods
Stove maker : Developed by CPRI and made by local agencies
Production method : Cutting,welding and punching sheet metal.
Price : Rs105-188

Figure 9. Improved vented stove



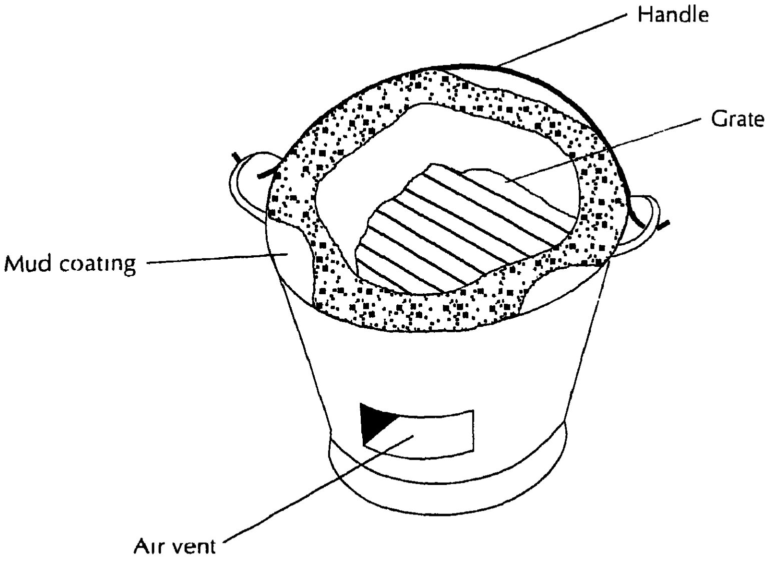
Country, places : All states of India
Fuel type : Fuel wood, twigs, crop residues and dung cakes
Material : Mud, clay, chimney, cowl
Stove maker : Trained local persons
Price : Rs 55-80

Figure 10. HARA



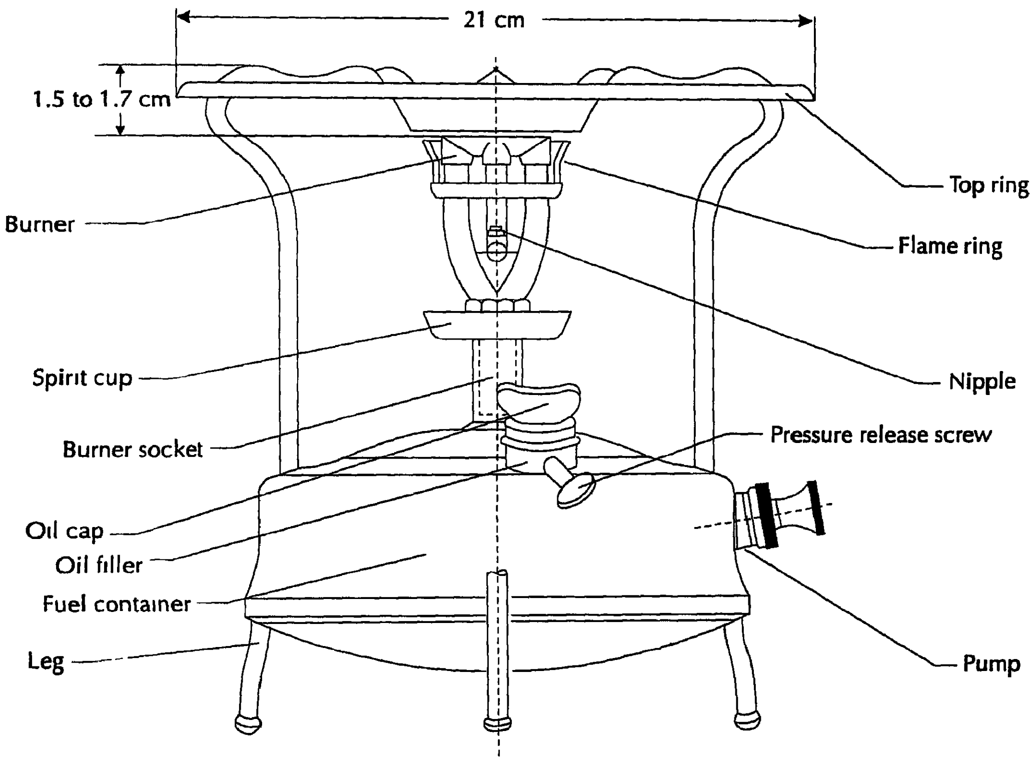
Country, places . Norther states of India, Open place, court yard of rural houses
User : Rural people who have cattles
Fuel type : Dung cake
Material : Mud, clay
Stove maker : User
Production method Dig a pit in the ground or make a vessel type arrangement with clay and mud.
Price′ : Nil

Figure 11 Angethi



Country, Places India, Rural and Urban areas
User . Rural and urban poor
Fuel type : Charcoal
Material . GI bucket, Grate, concrete
Stove maker : Local vendors
Production method : Coat the GI bucket with concrete, divide into halves by the grate
Price : Rs 100

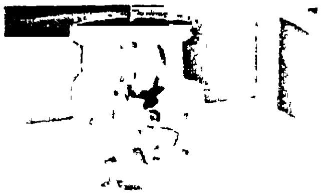
Figure 12 . Kerosene Pressure Stove



Country, Places : All parts of India

User : Kerosene fuel user
Fuel type : erosene
material : Brass metal sheet, metal rods and plates
Stove maker : Local vendors
Production method : Cutting, welding and punching the metal sheets
Price : Rs 250 - 300

Figure 13 Stoves tested in the study



a. Traditional mud

b. Hara

c. Angethi

d. Improved vented

e. Three rock

f. Unproved unvented

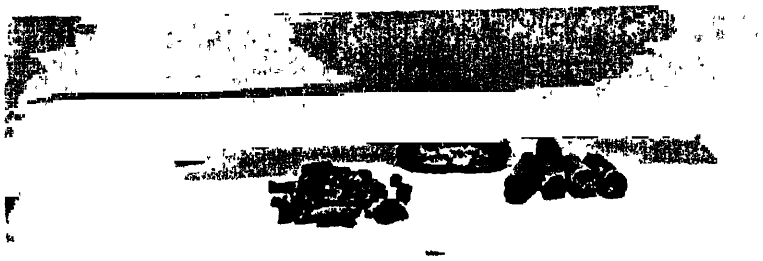
g. Kerosene pressure

h. Kerosene wick

Figure 14 Solid Fuels tested in the study

a. Wood I (Eucalyptus) b. Wood II (Acacia) c. Root fuel

d. Crop residue I (Mustard stalk) e. Crop residue II(Paddy straw)



f. Charcoal g. dung cake h. Char briquette

Figure 15. Power input for various fuel/stove combinations

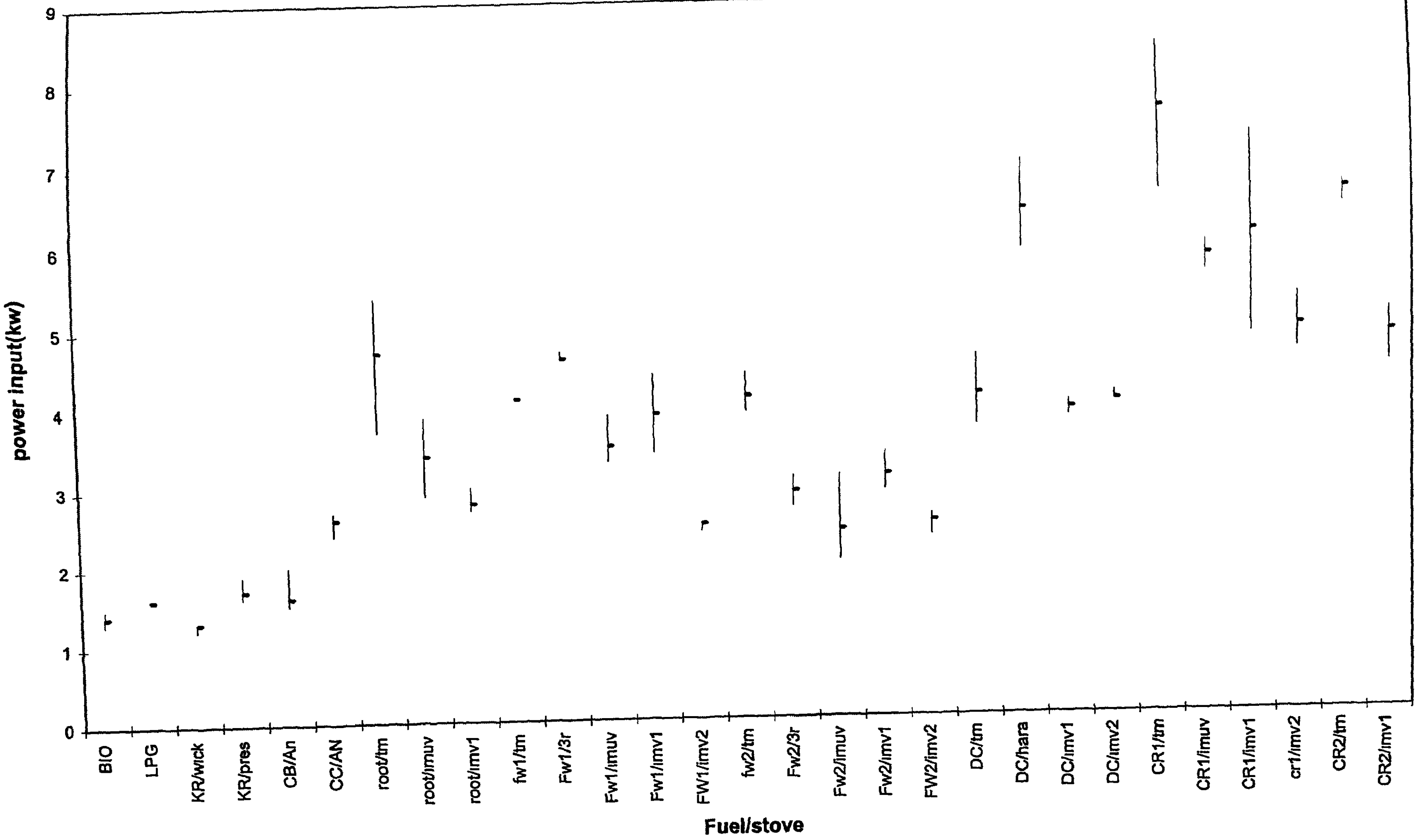


Figure 16. Efficiency of different fuel/stove tested

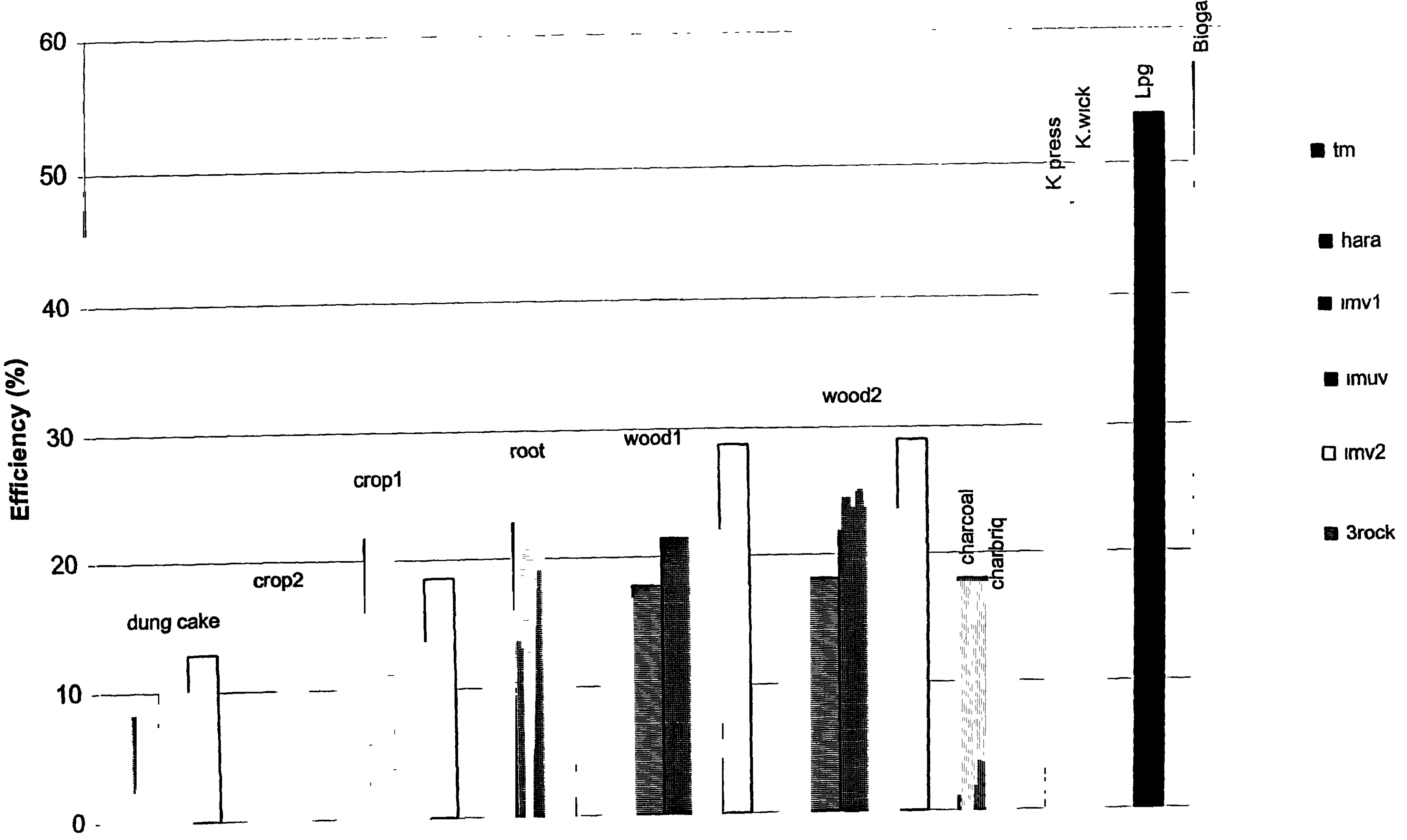
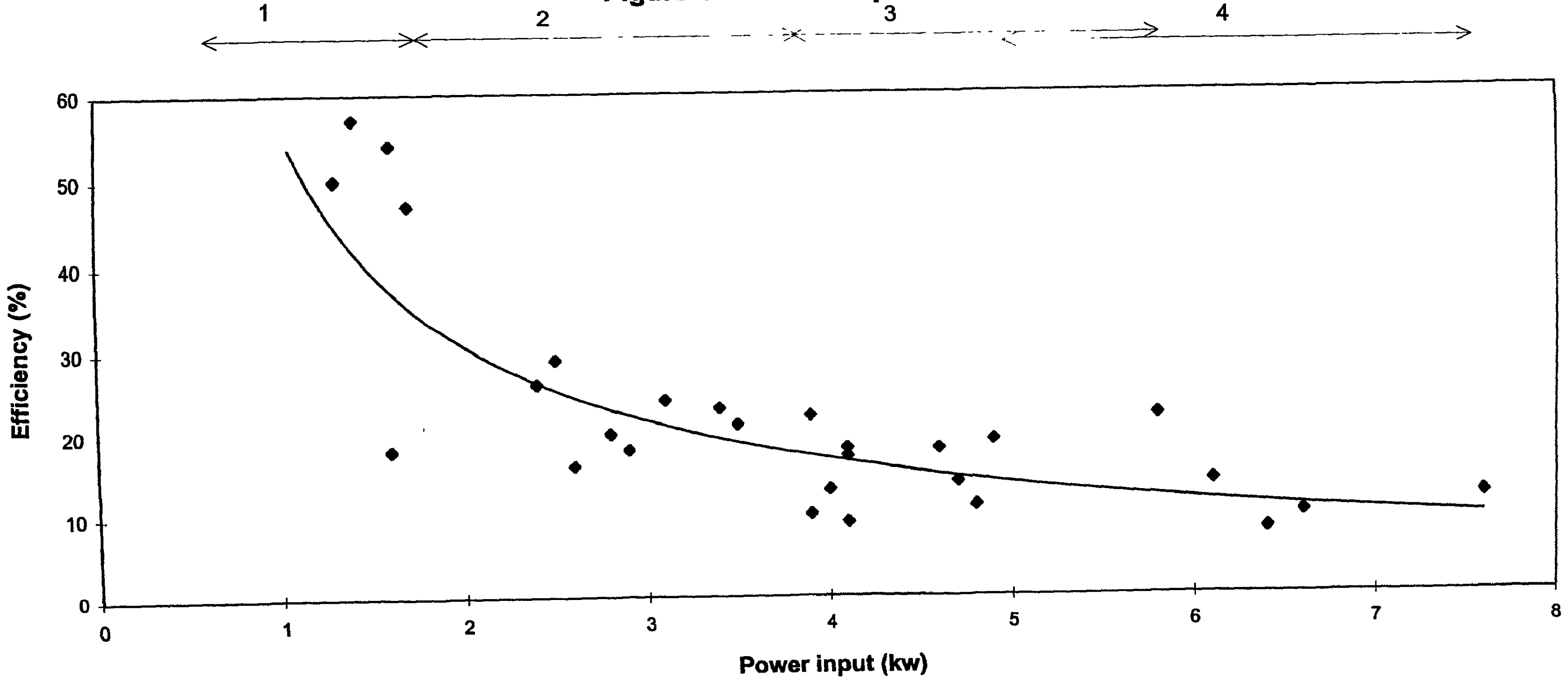


Figure 17. Power input Vs Efficiency



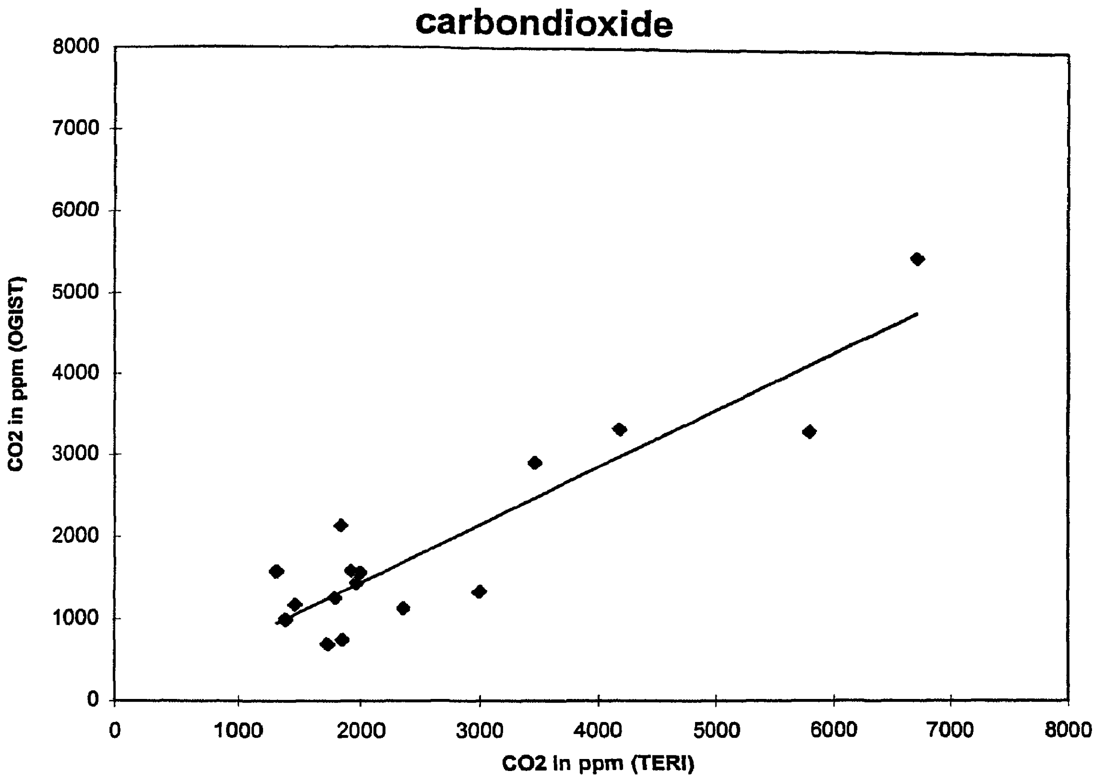
1. Lpg, Bio, Kero, CB

2. Wood, Char coal, Root

3. Dung cake

4. Crop residue

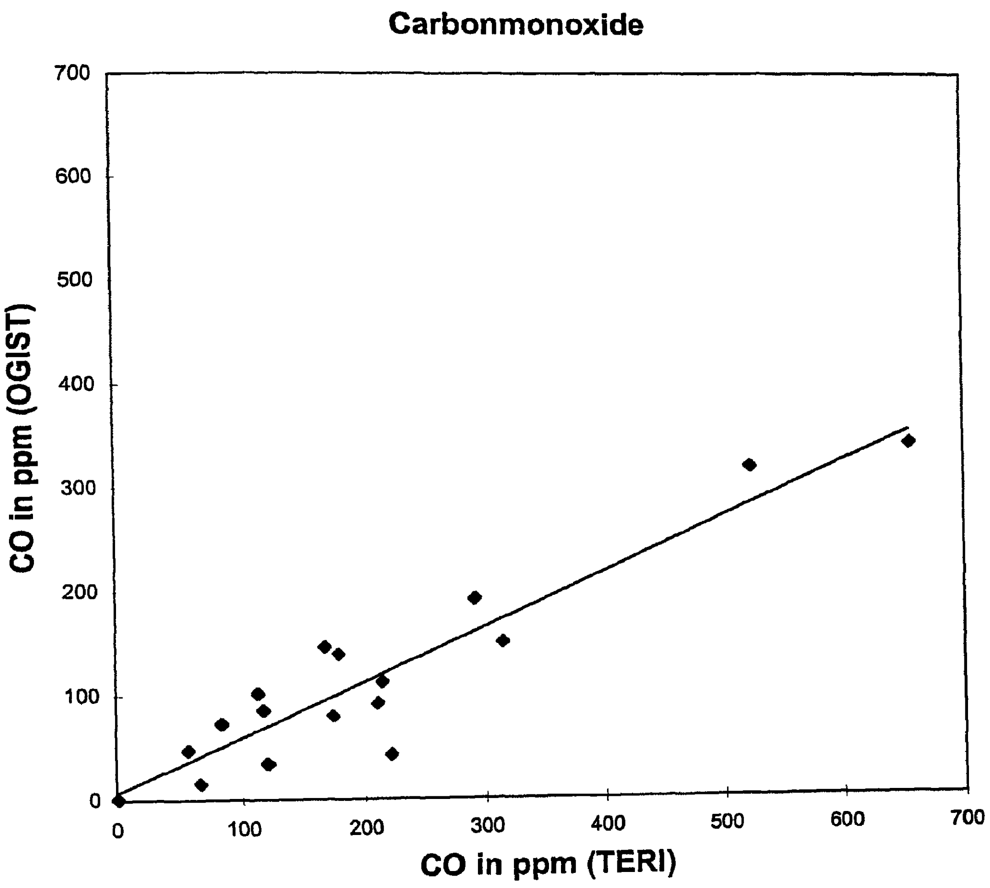
Figure. 18 **Regression analysis for CO2 (TERI Vs OGIST)**



Regression Statistics

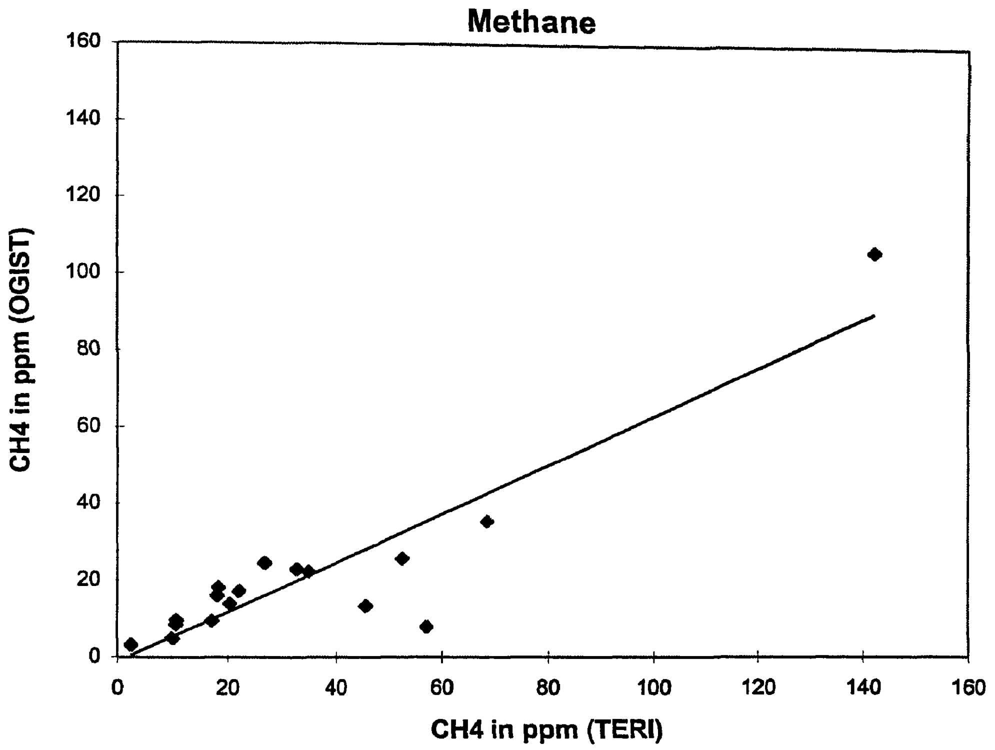
R Square 0.82
X Variable (m) . 0.71
Intercept (C) 15 1

Figure 19. Regression analysis for CO (TERI Vs OGIST)



Regression Statistics
R Square 0 87
Intercept (C) 6 66
X variable (m) 0.529

Figure 20. **Regression analysis for CH4 (TERI Vs OGIST)**



Regression Statistics

R Square	0 82
X Variable (m)	0 639
Intercept (C)	-1.12

Figure 21. CO2 Emission factor(g/kg) for various fuel/stove tested

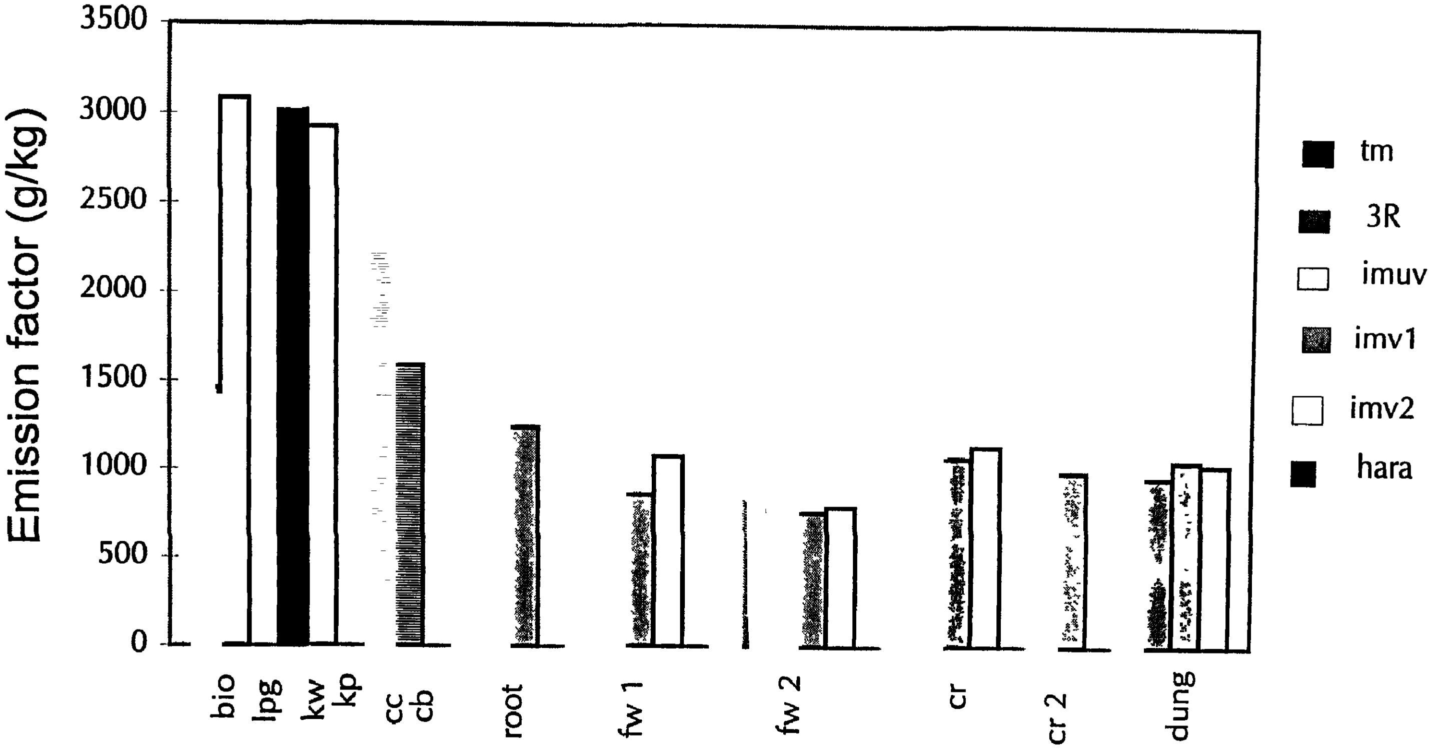


Figure 22. CO Emission factor(g/kg) for various fuel/stove tested

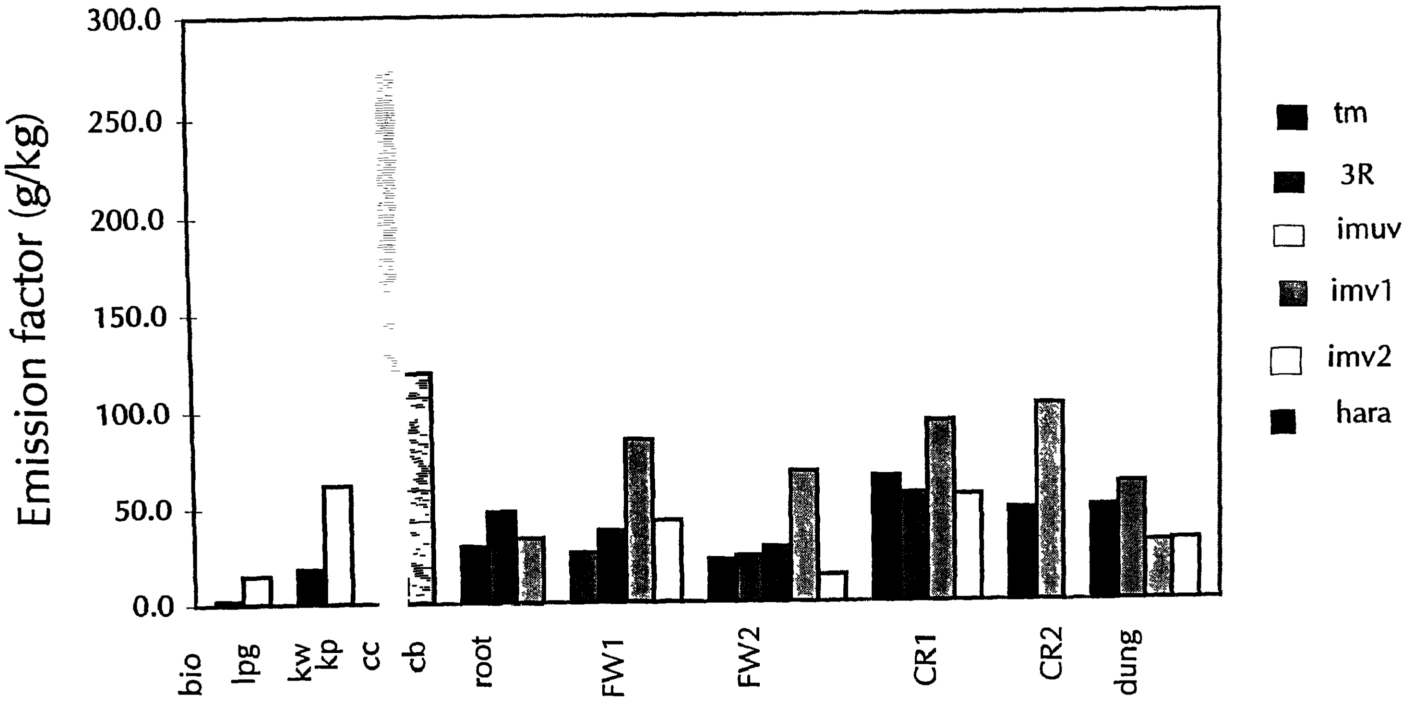


Figure 23. CH4 Emission factor(g/kg) for various fuel/stove tested

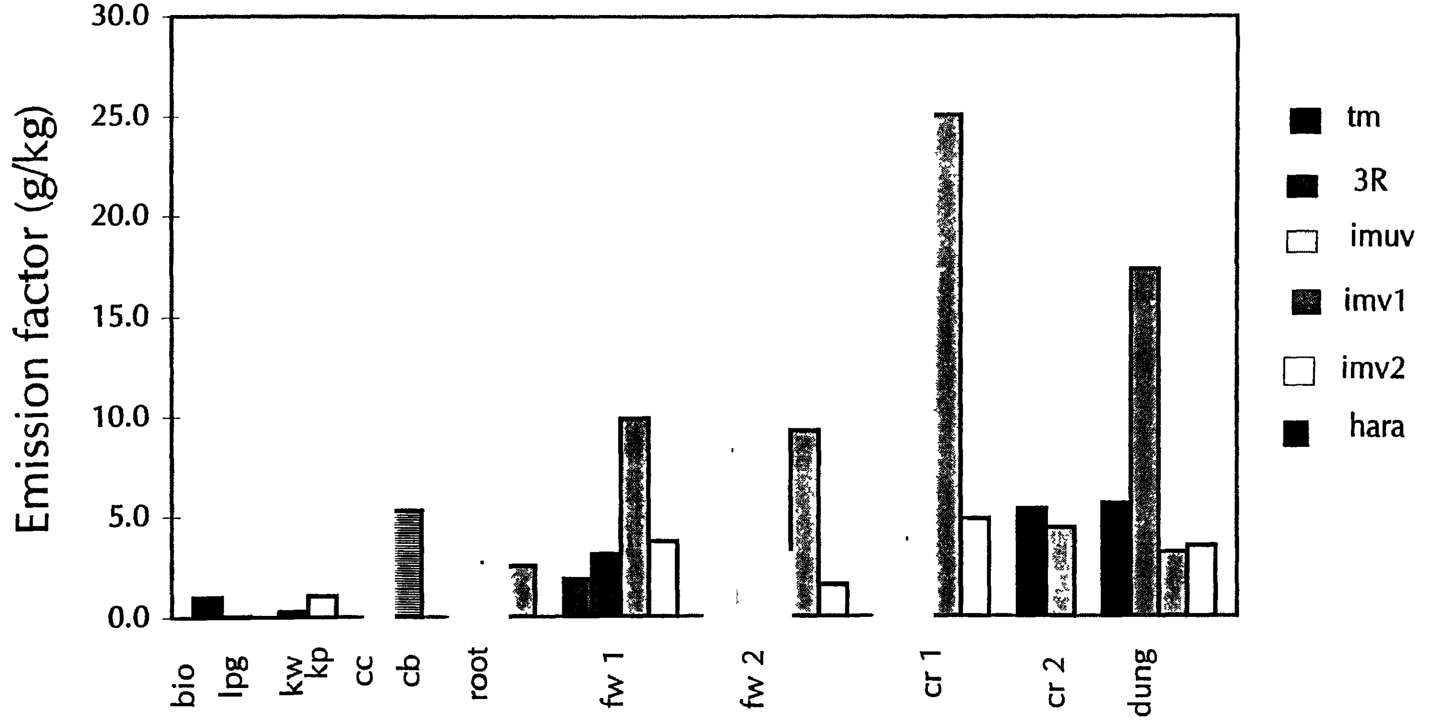


Figure 24. TNMOC Emission factor(g/kg) for various fuel/stove tested

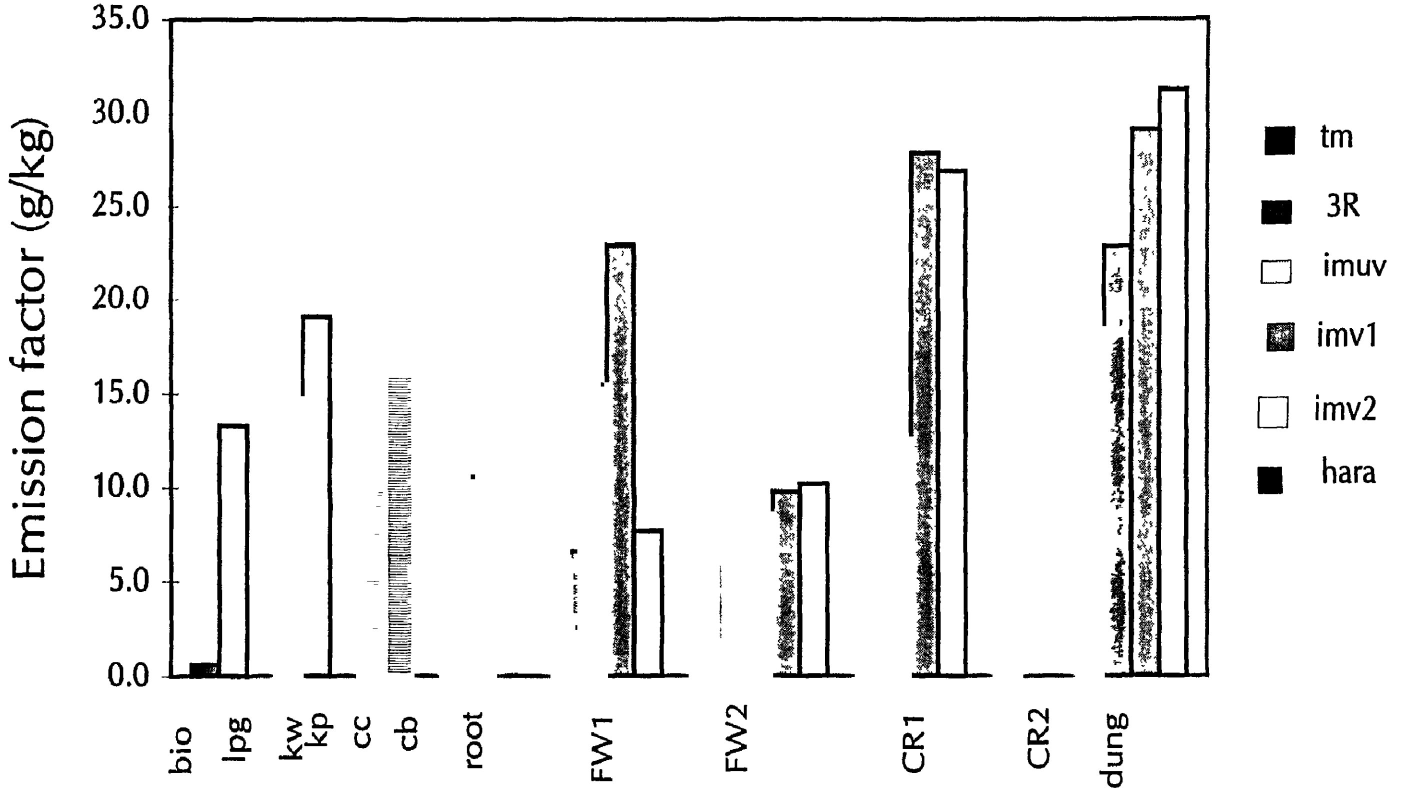
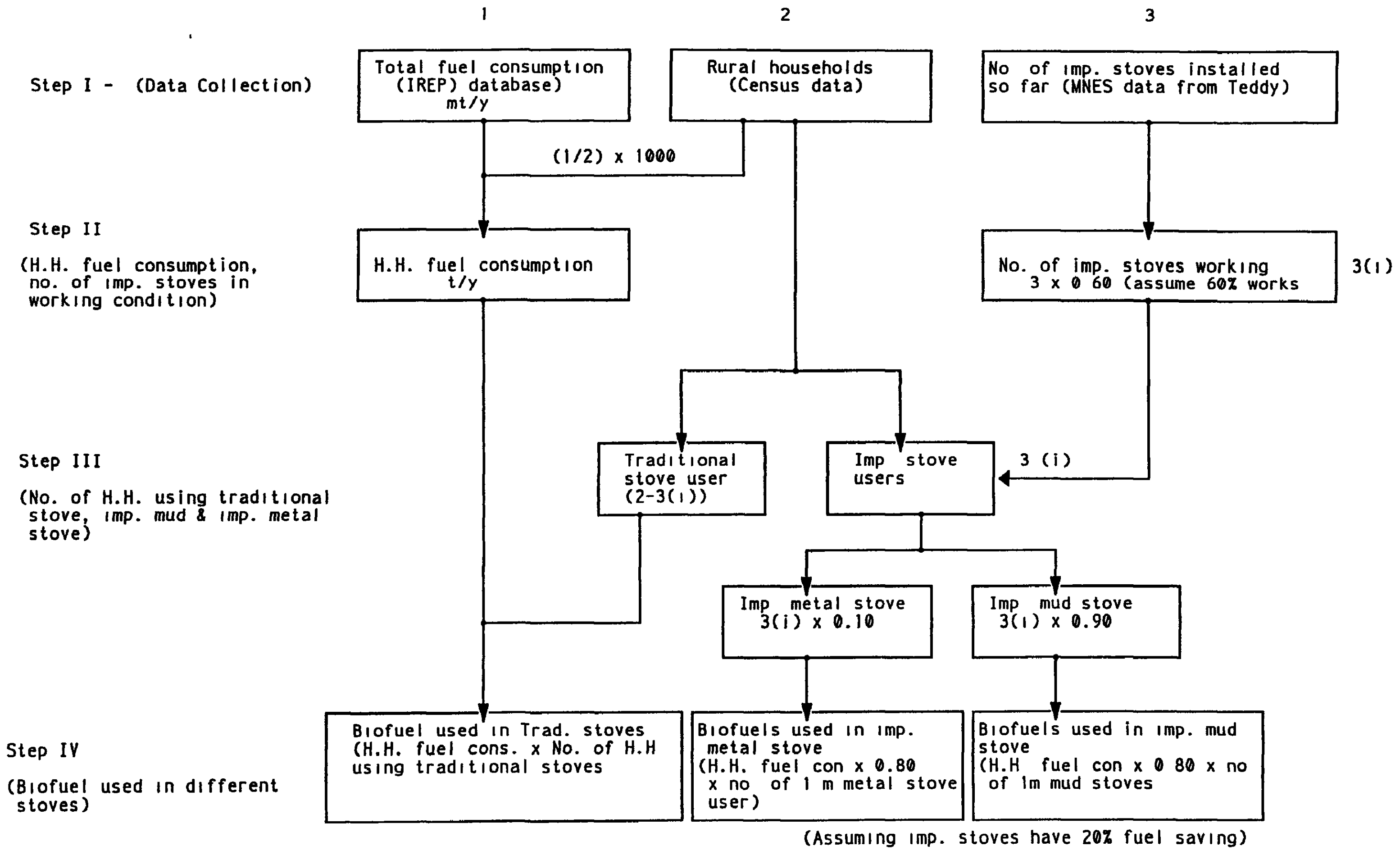


Figure 25. Biofuel estimation for Rural India


1
2
3
Step I - (Data Collection)
Total fuel consumption (IREP) database) mt/y
Rural households (Census data)
No of imp. stoves installed so far (MNES data from Teddy)
(1/2) x 1000
Step II
(H.H. fuel consumption, no. of imp. stoves in working condition)
H.H. fuel consumption t/y
No. of imp. stoves working 3 x 0 60 (assume 60% works
3(i)
Step III
(No. of H.H. using traditional stove, imp. mud & imp. metal stove)
Traditional stove user (2-3(i))
Imp stove users
3 (i)
Imp metal stove 3(i) x 0.10
Imp mud stove 3(i) x 0.90
Step IV
(Biofuel used in different stoves)
Biofuel used in Trad. stoves (H.H. fuel cons. x No. of H.H using traditional stoves
Biofuels used in imp. metal stove (H.H. fuel con x 0.80 x no of 1 m metal stove user)
Biofuels used in imp. mud stove (H.H fuel con x 0 80 x no of Im mud stoves
(Assuming imp. stoves have 20% fuel saving)